JULY 1960
Volume 195 Part 3

Established 1869
Incorporated by Royal Charter 1899

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JOURNAL OF THE IRON AND STEEL INSTITUTE

BOTH BRITAIN'S NEW HOT STRIP MILLS ARE BEING BUILT BY DAVY-UNITED

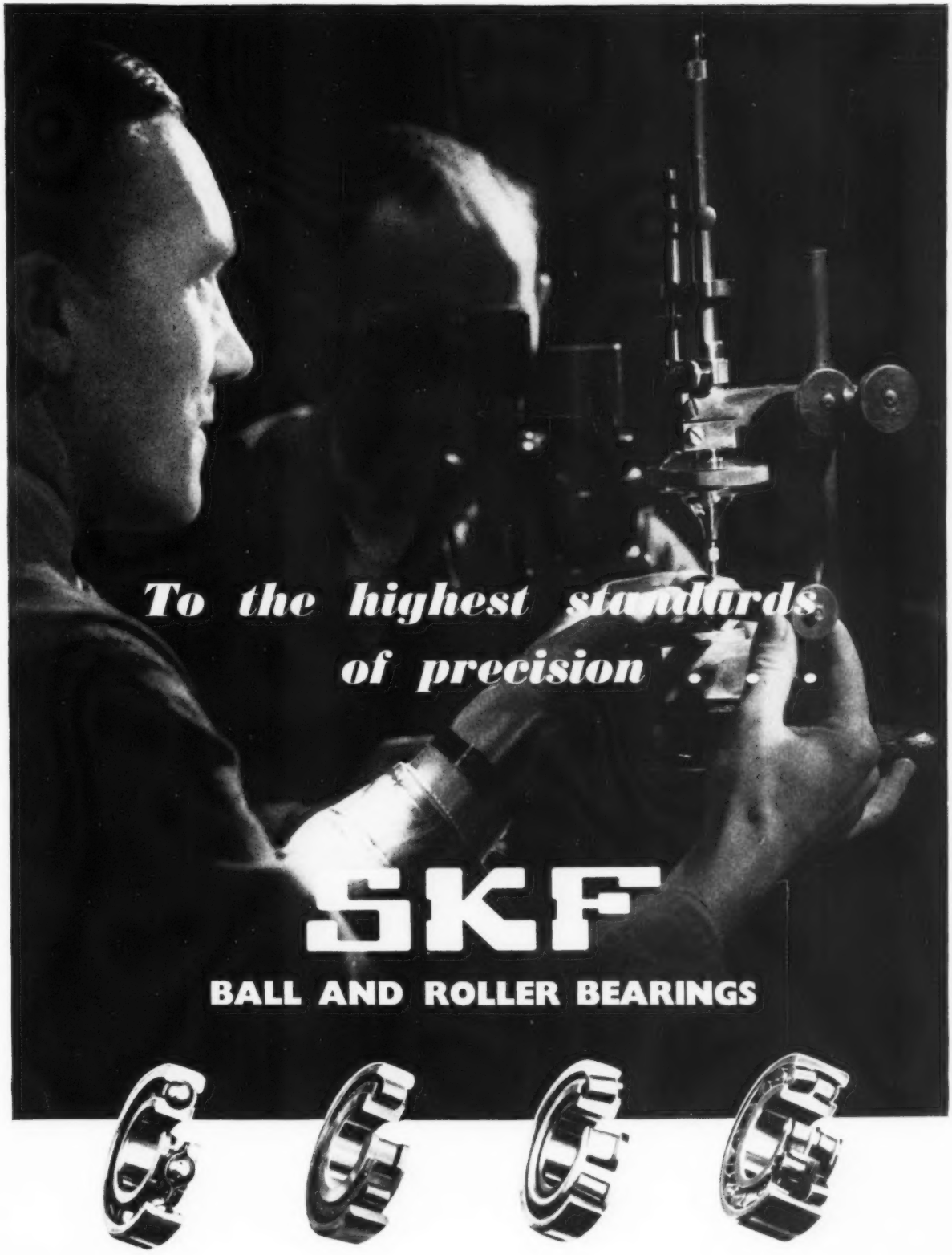
The famous Hot Strip Mill at the Ebbw Vale Works of Richard Thomas & Baldwins Limited the first in Europe, which Davy-United also helped to build. This photograph shows the mill at the completion of an extensive modernisation scheme in August, 1959, after nearly 21 years of continuous production

Two new Hot Strip Mills are now being built in Britain – the first at the Ravenscraig Works of Colvilles Limited: the second at the Spencer Works at Newport, Mon., of Richard Thomas and Baldwins Limited. Davy-United have been entrusted with the building of both of them.

DAVY-UNITED

370/DU

Davy and United Engineering Company Limited, Sheffield, England



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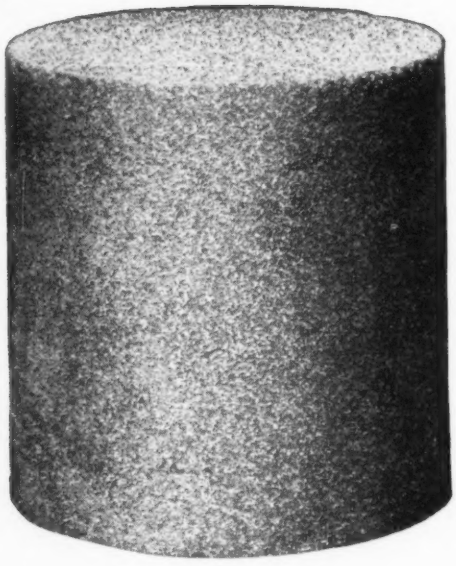

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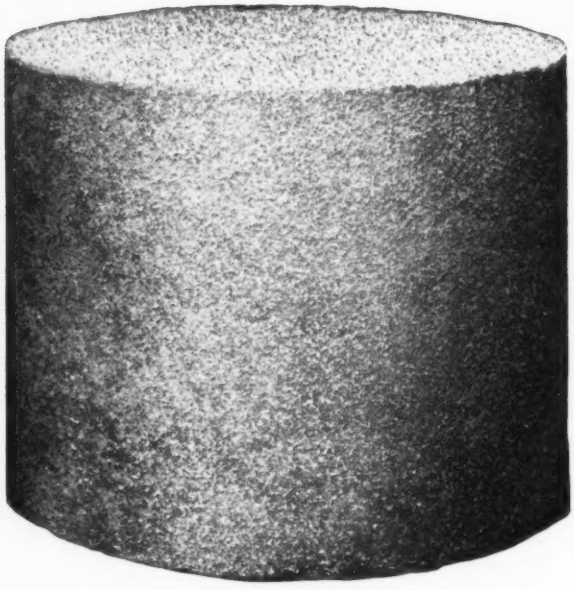

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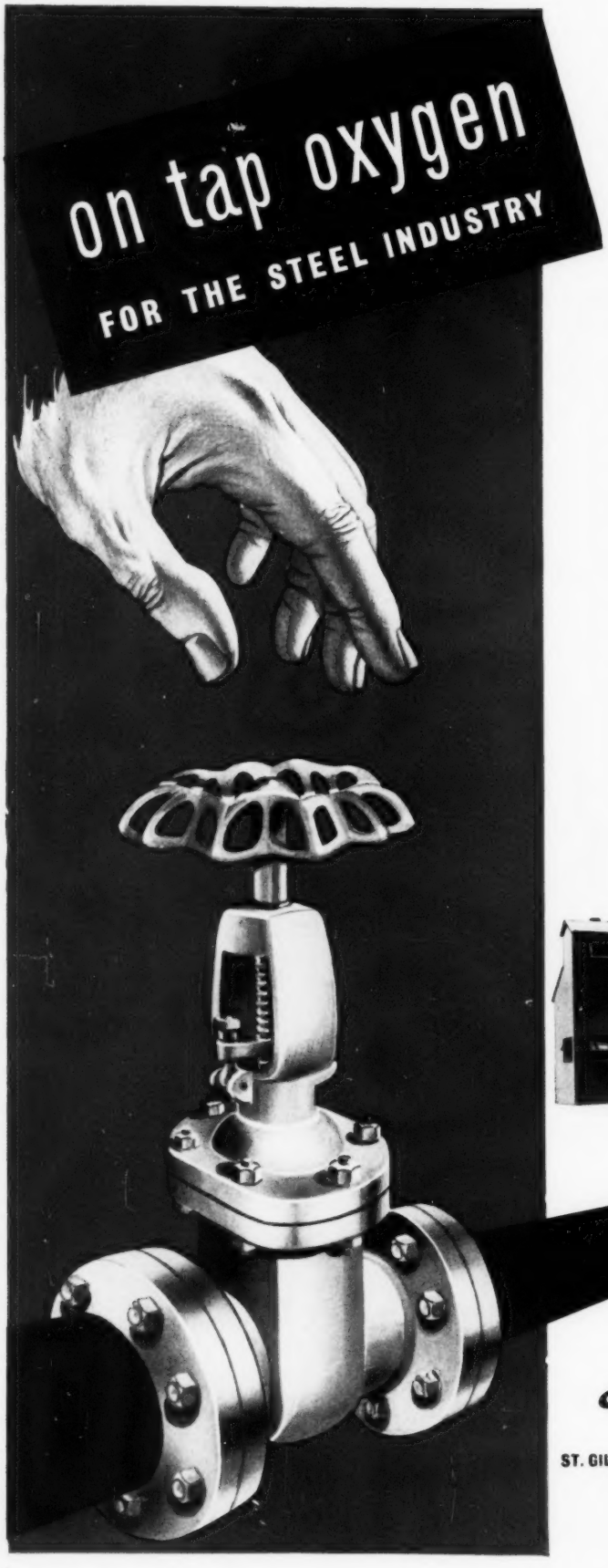

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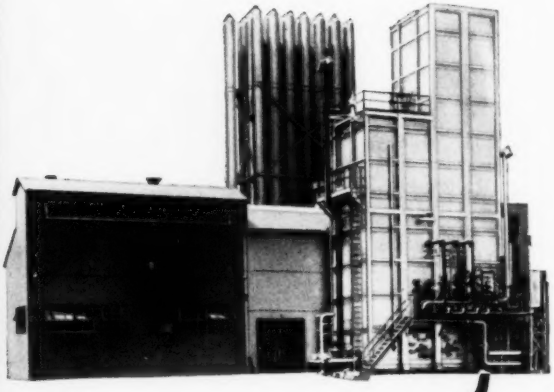

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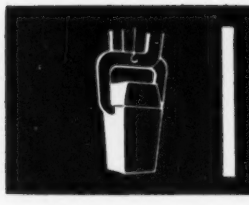

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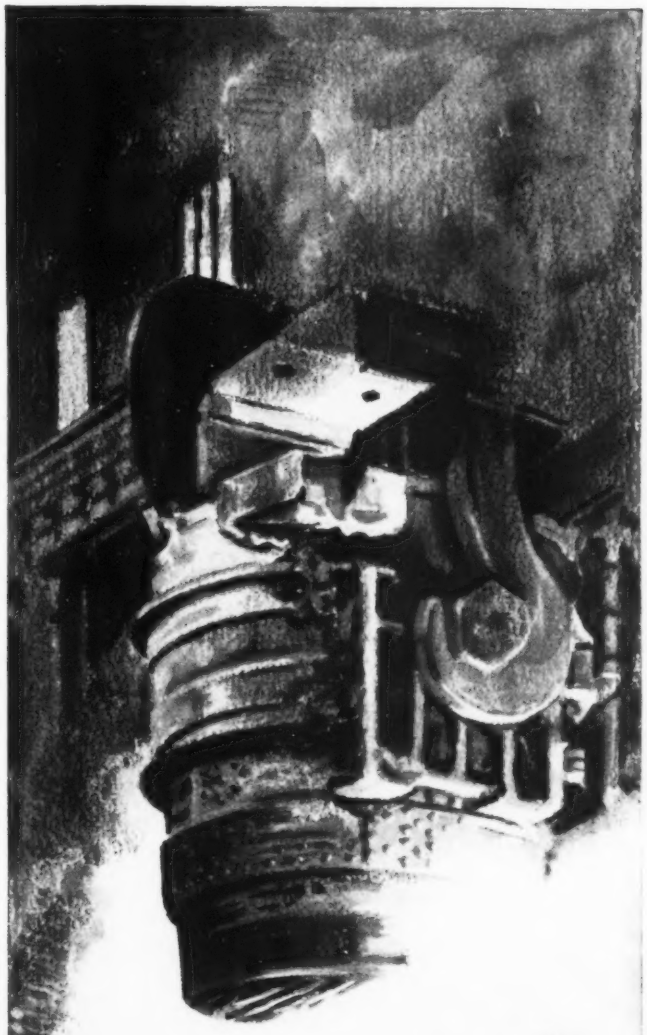

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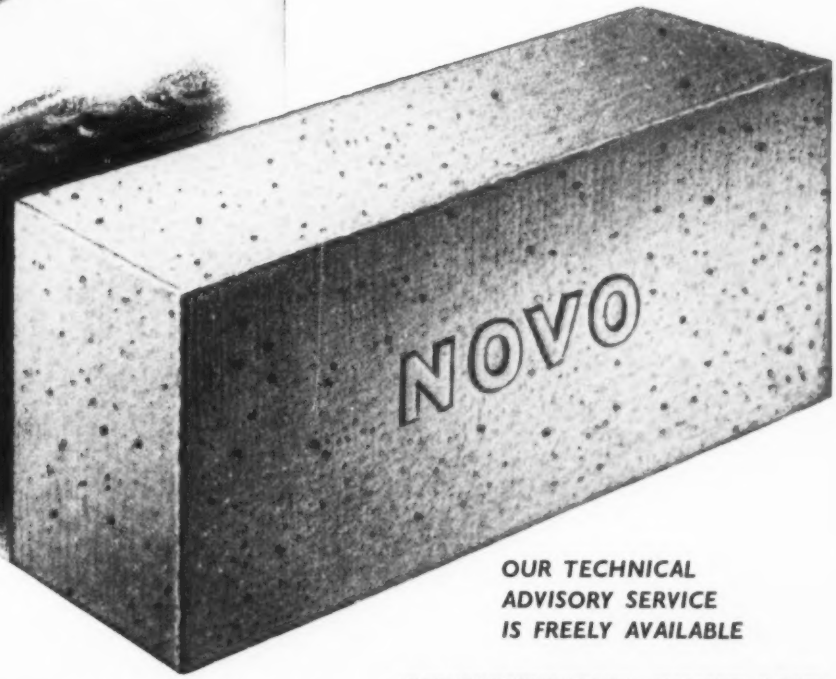

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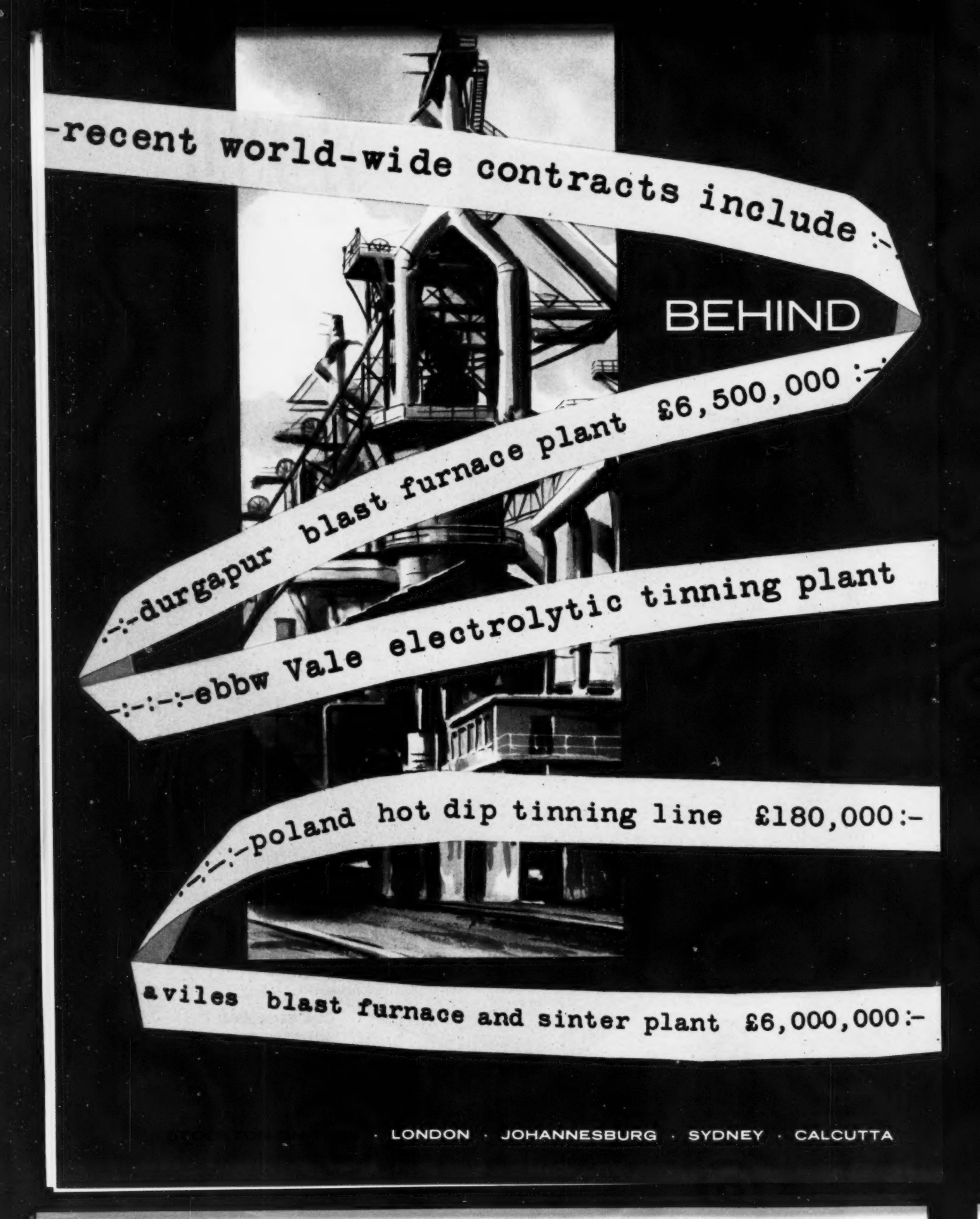
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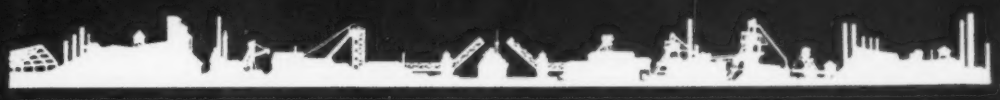

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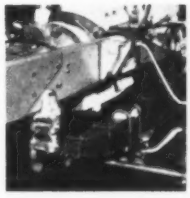

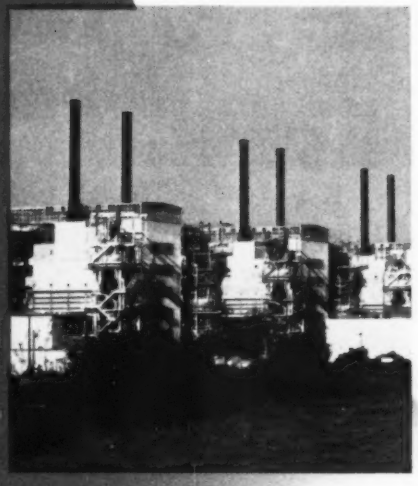

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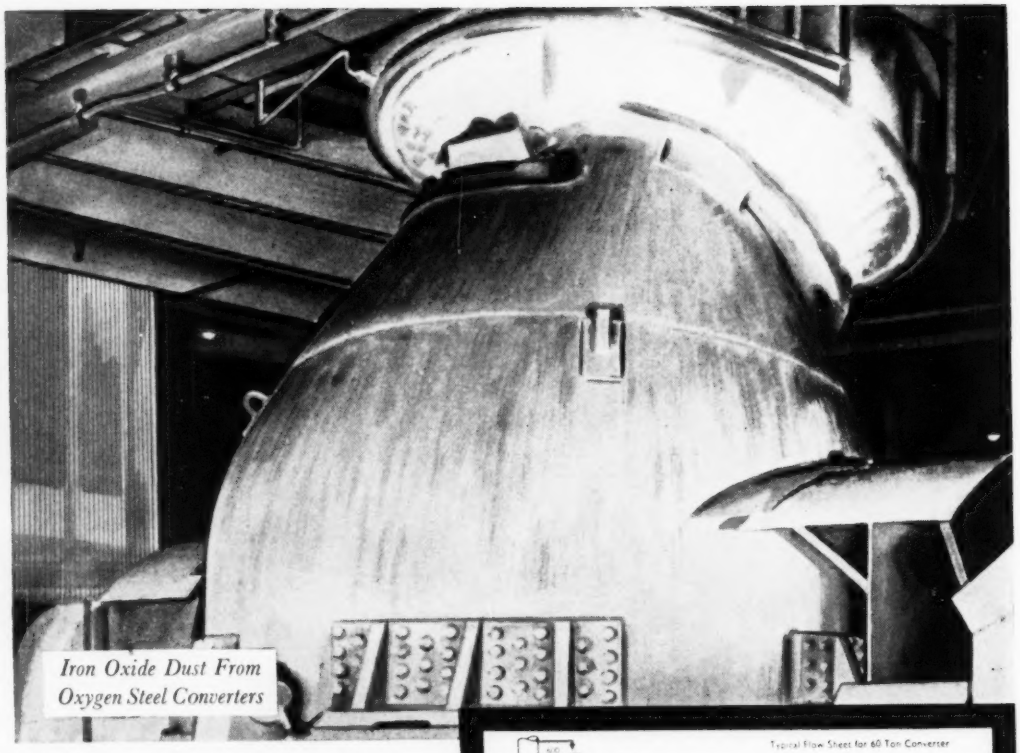

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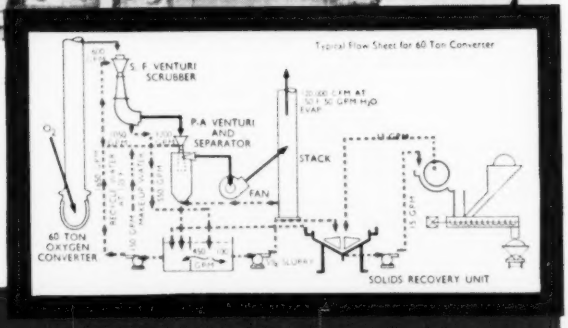

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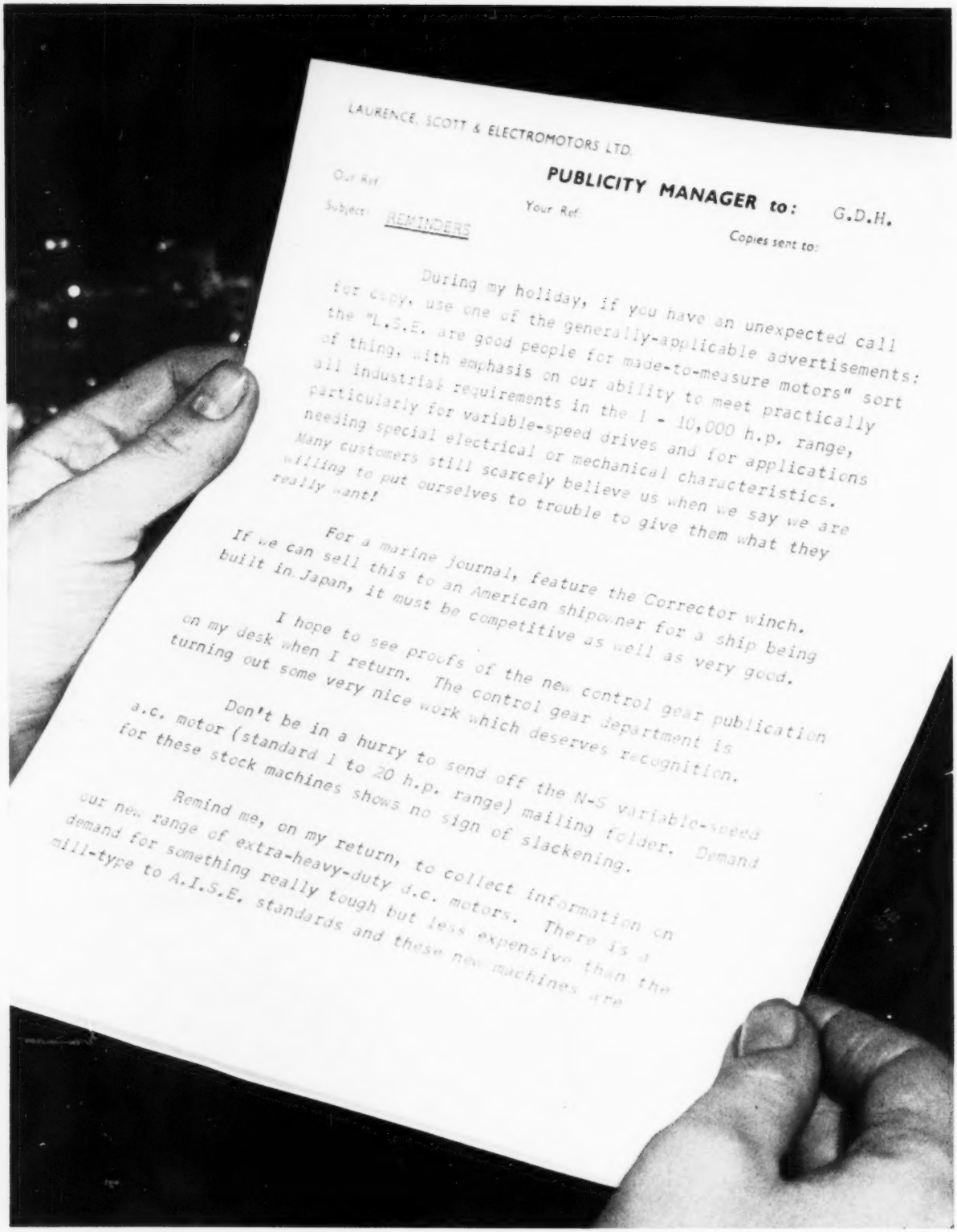
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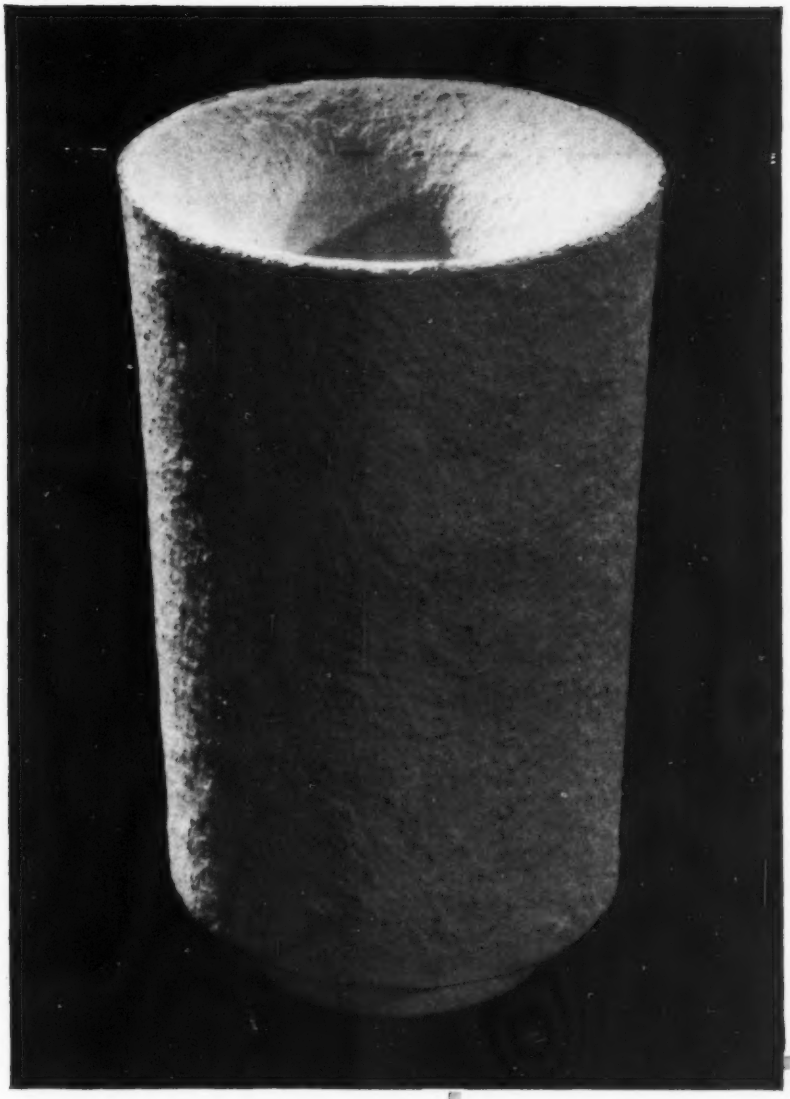

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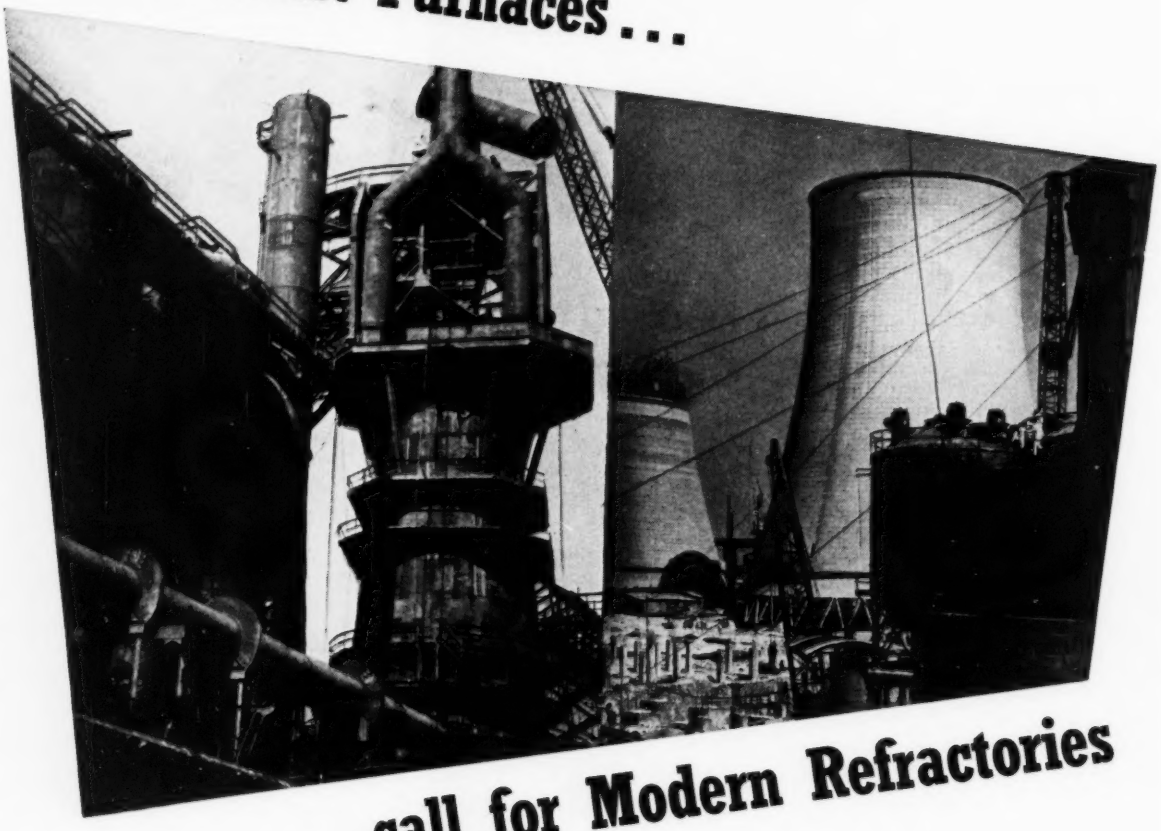

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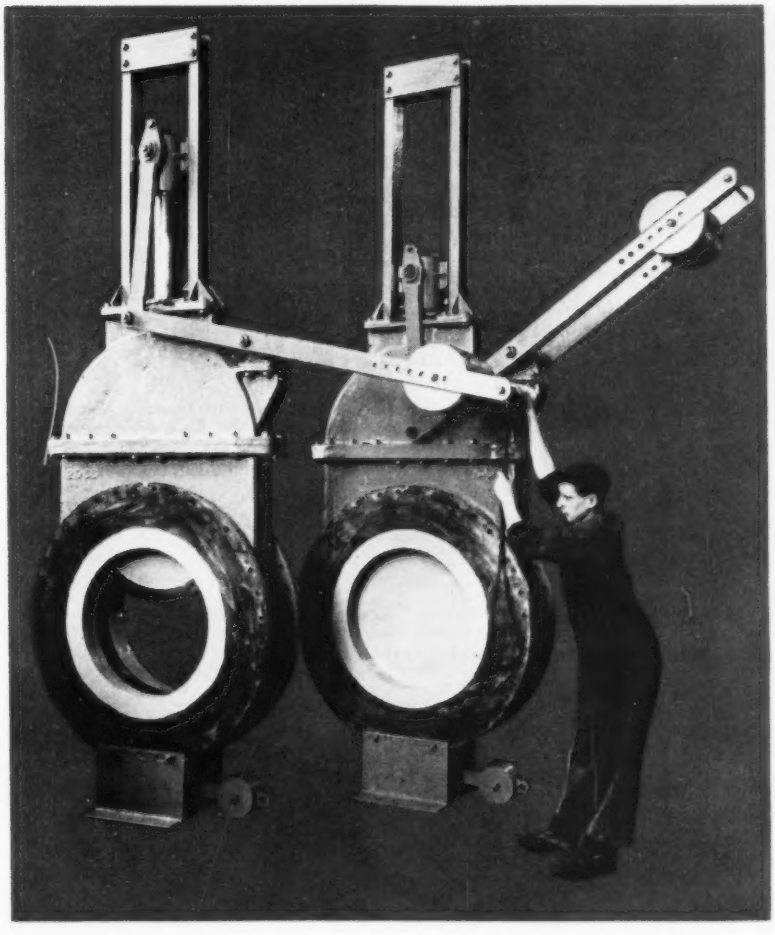

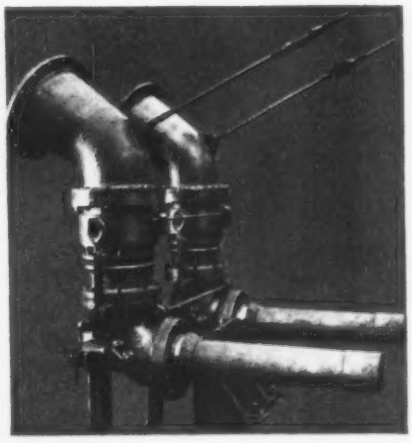

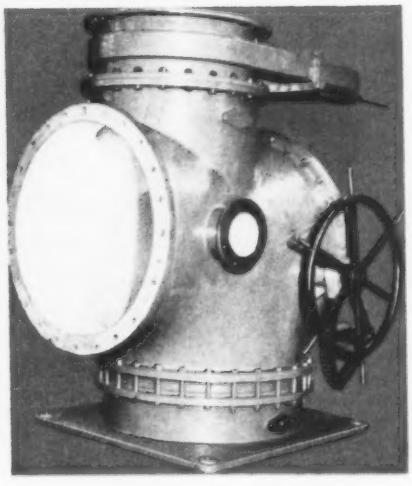

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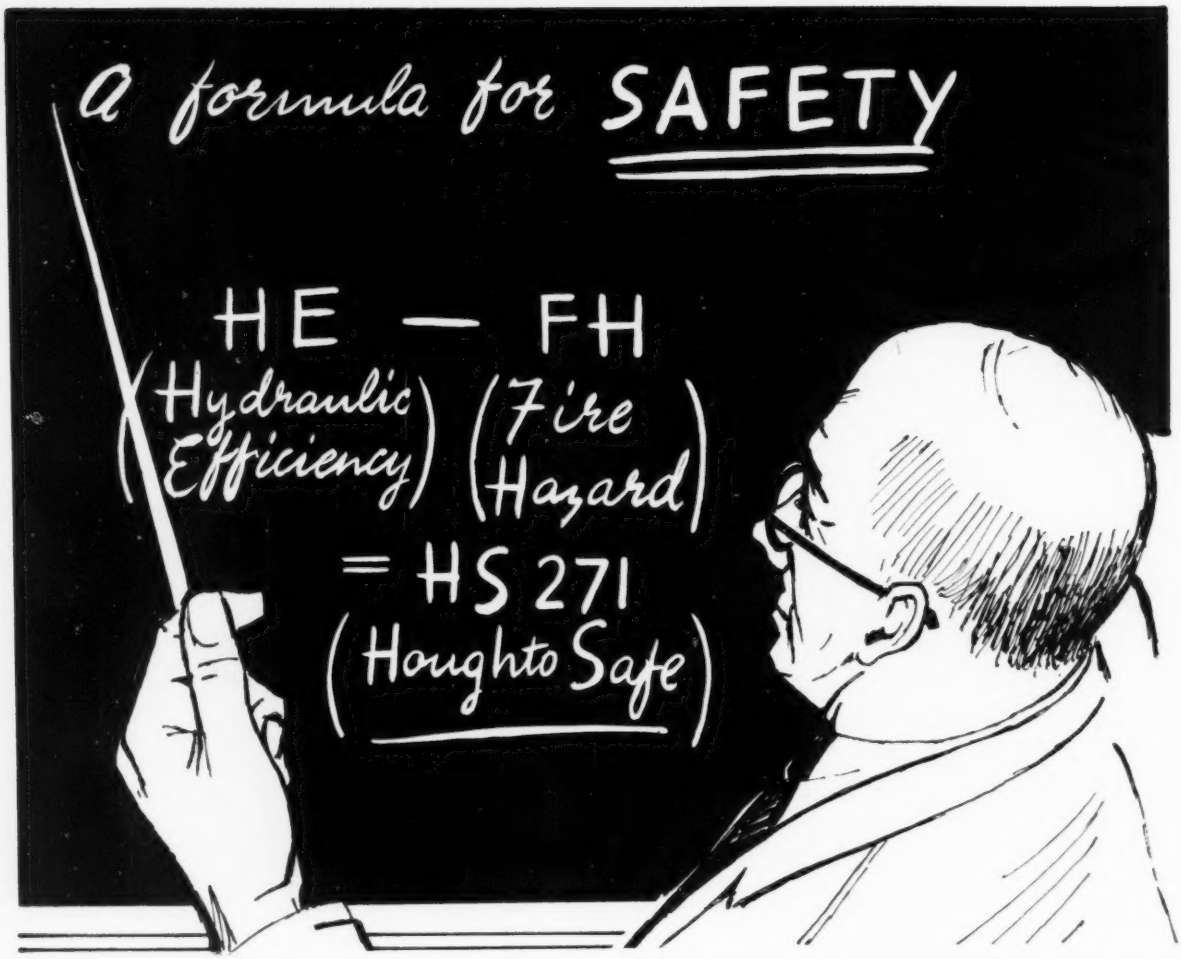

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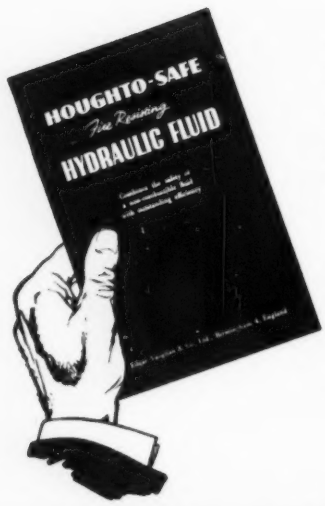

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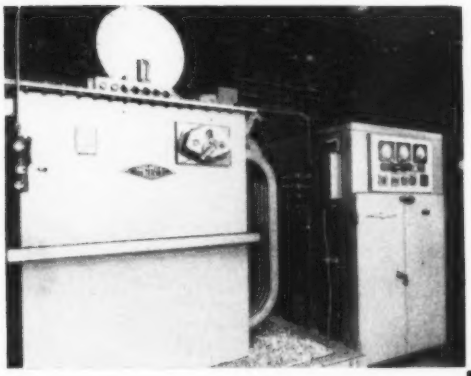

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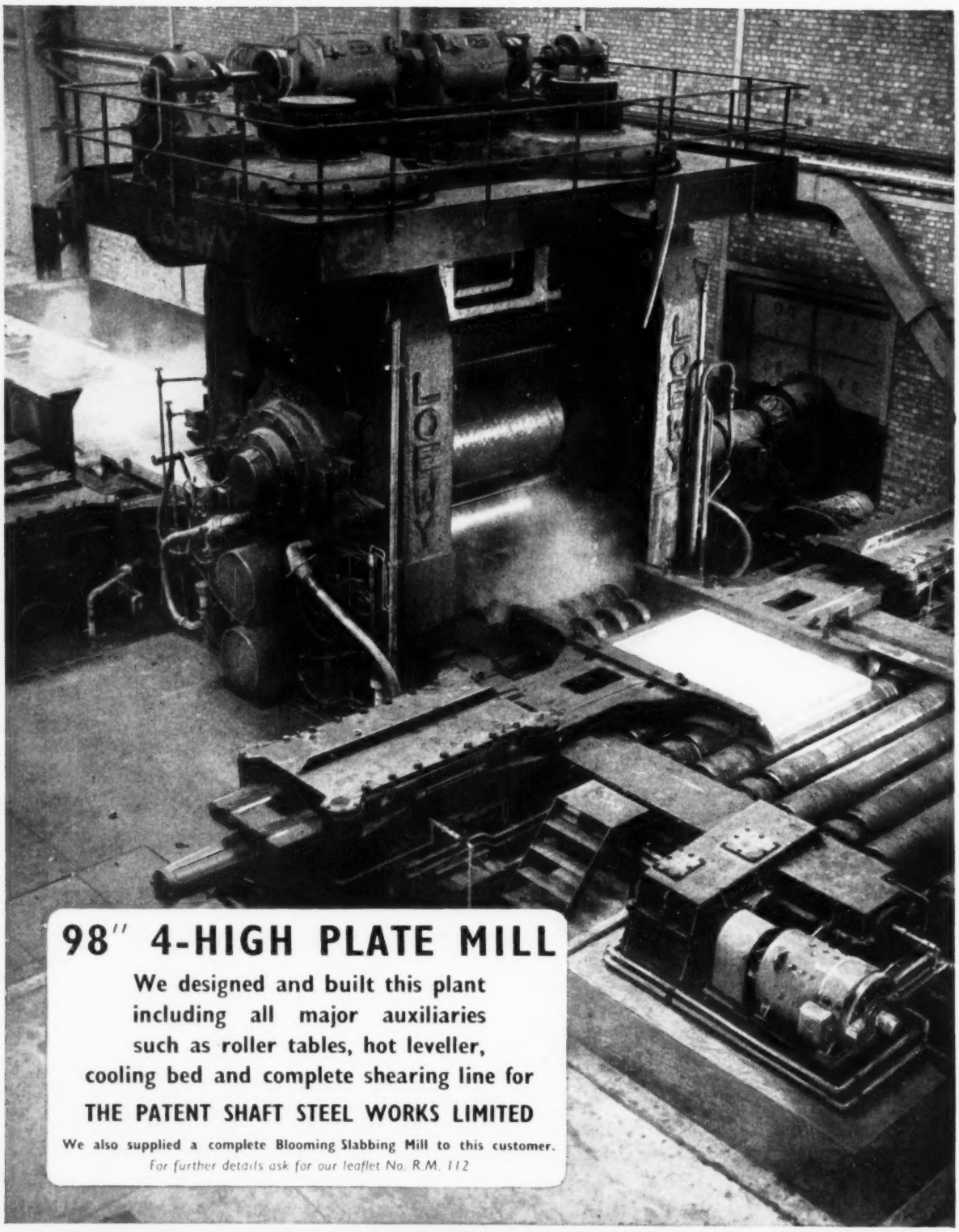

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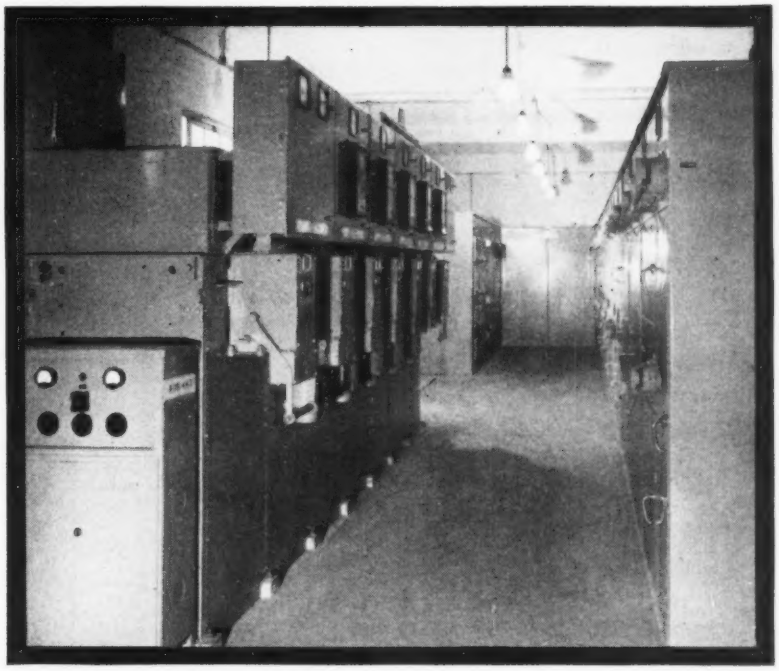

Equipment illustrated is typical of the multi-panel contractor boards, switchboards and supervisory control stations supplied to the orders of Messrs. Huntingdon, Heberlein & Co. Ltd., Moxey Ltd., and the Dalyte Electrical Co. Ltd. *Photographs by courtesy of The Stanton Ironworks Co. Ltd.*

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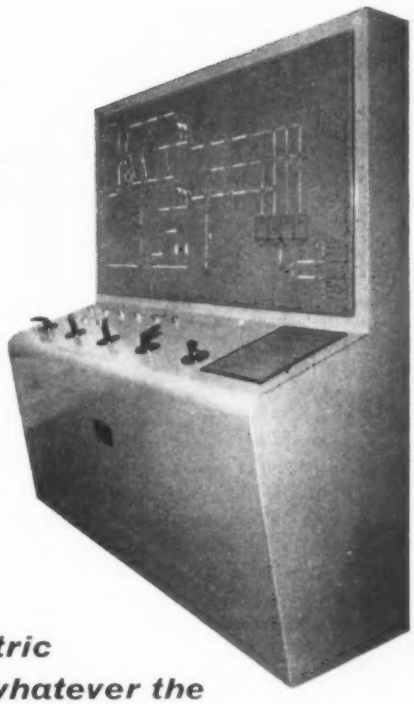

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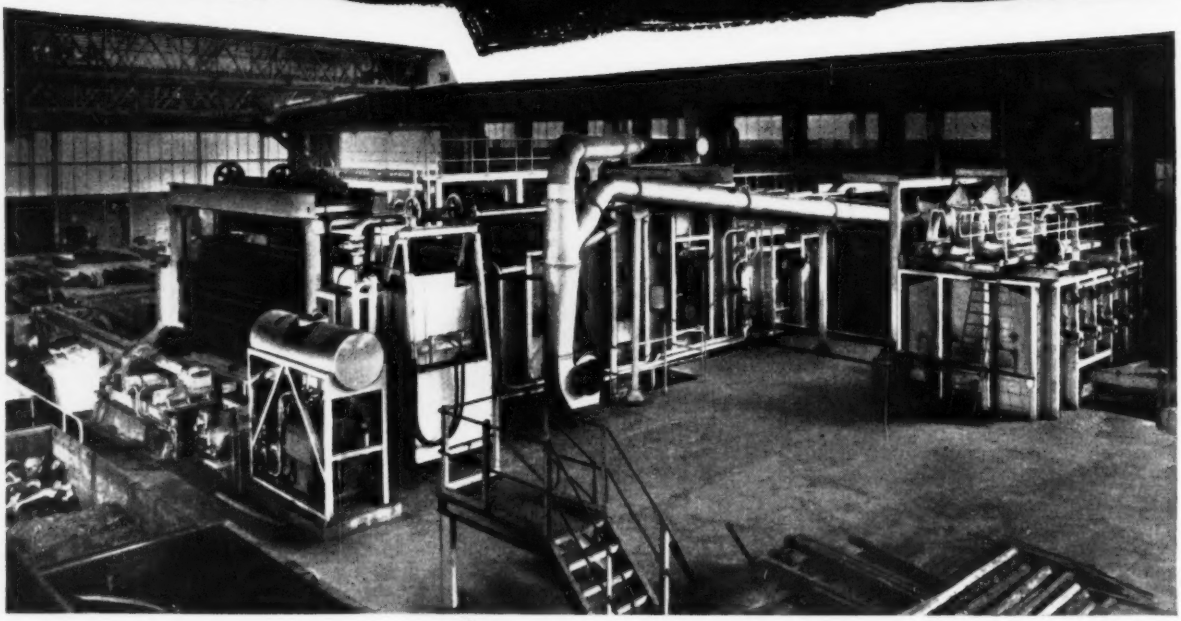

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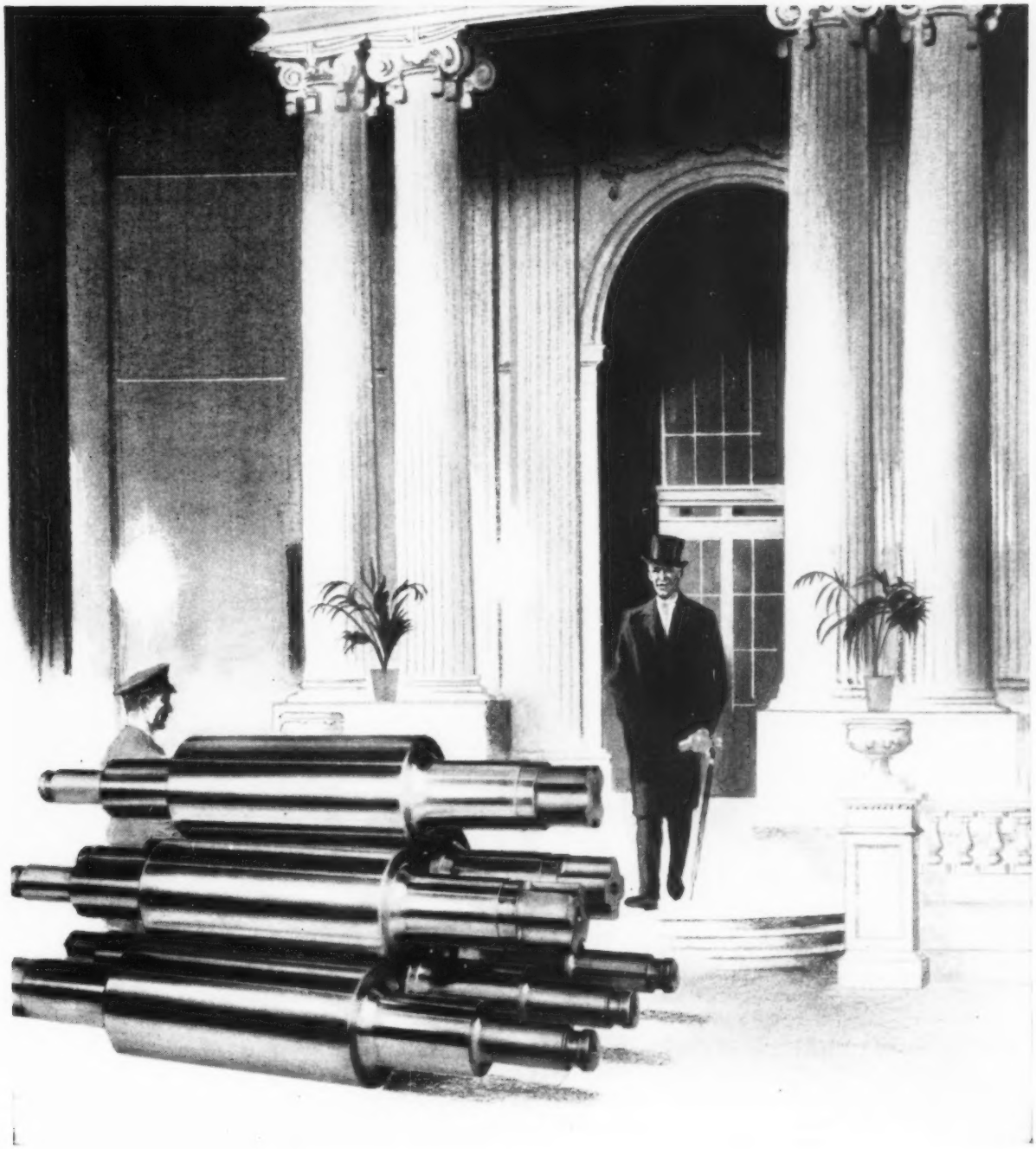

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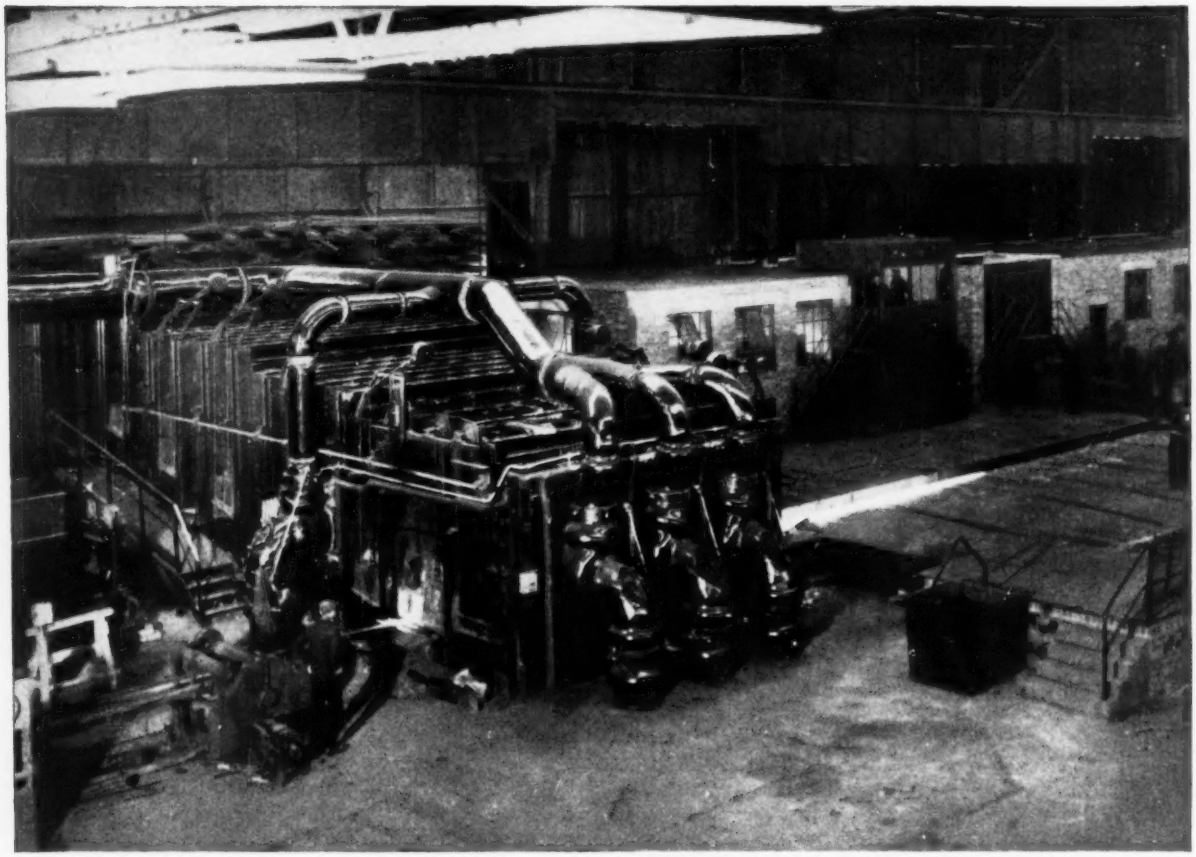

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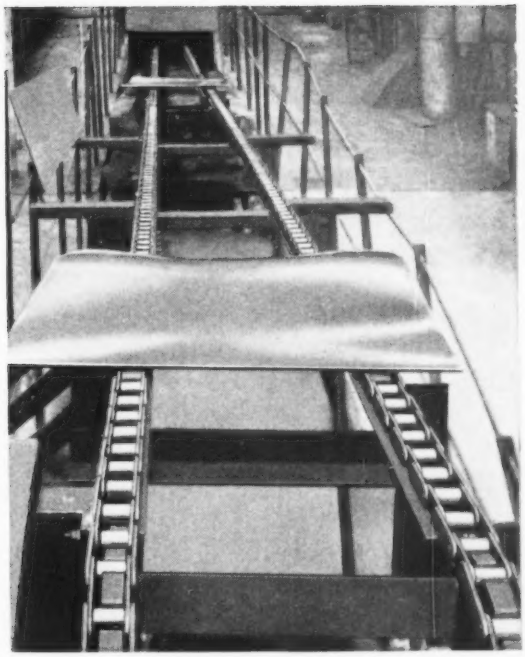

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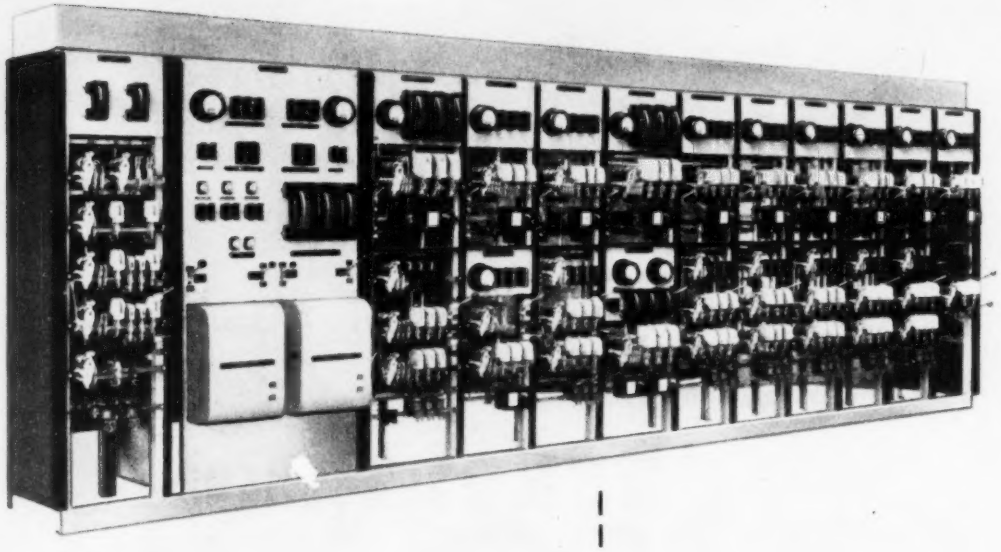

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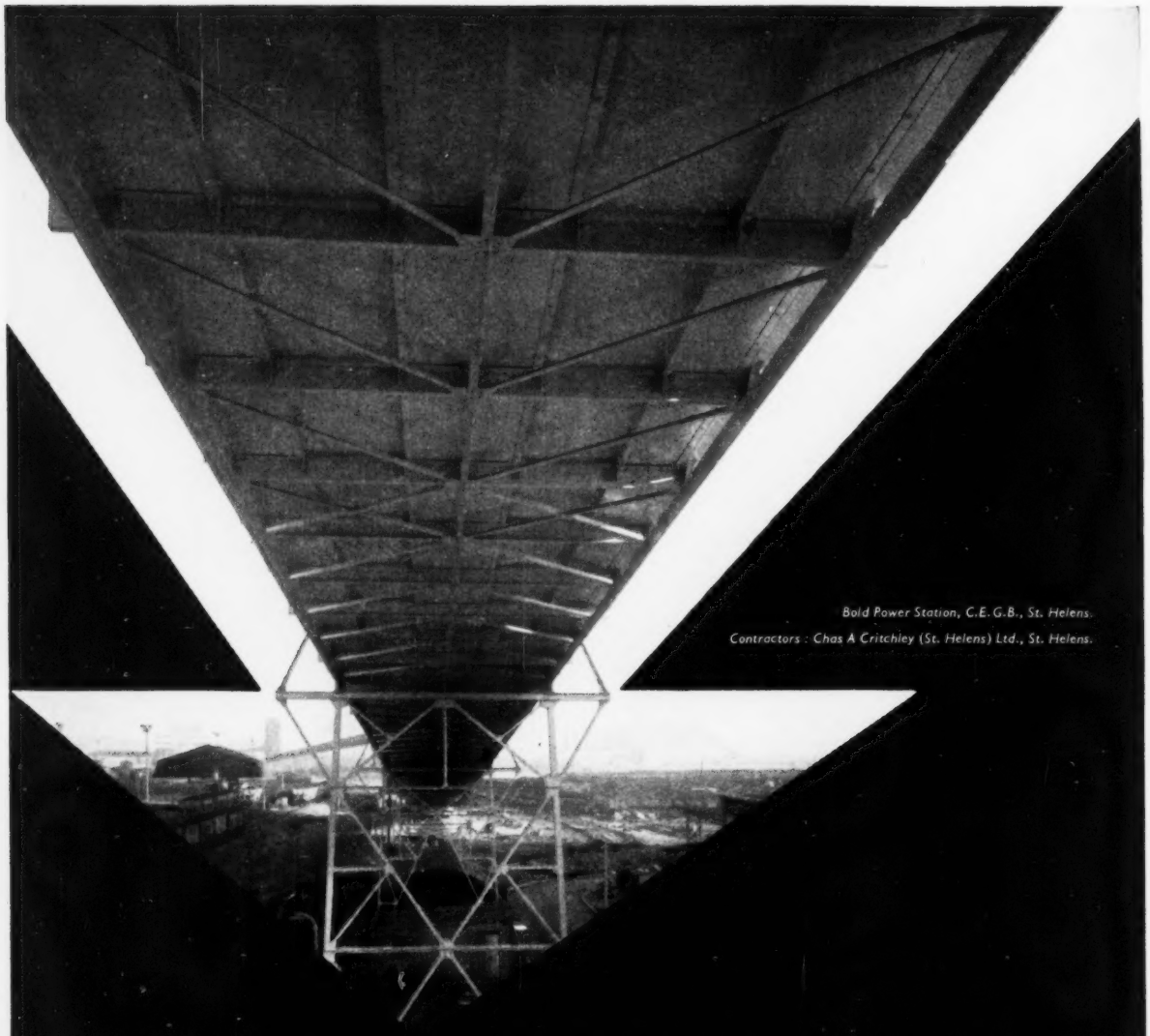

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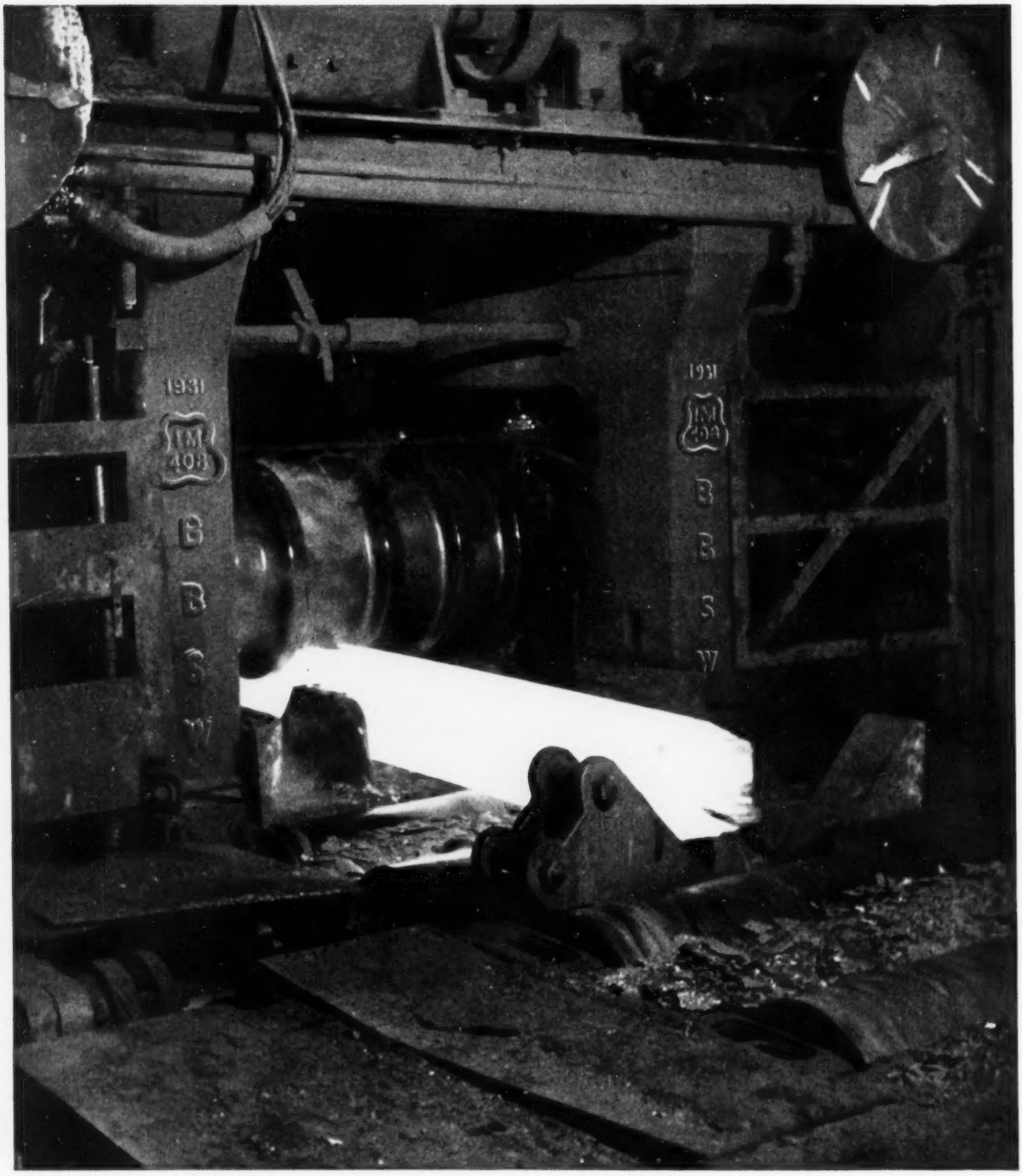

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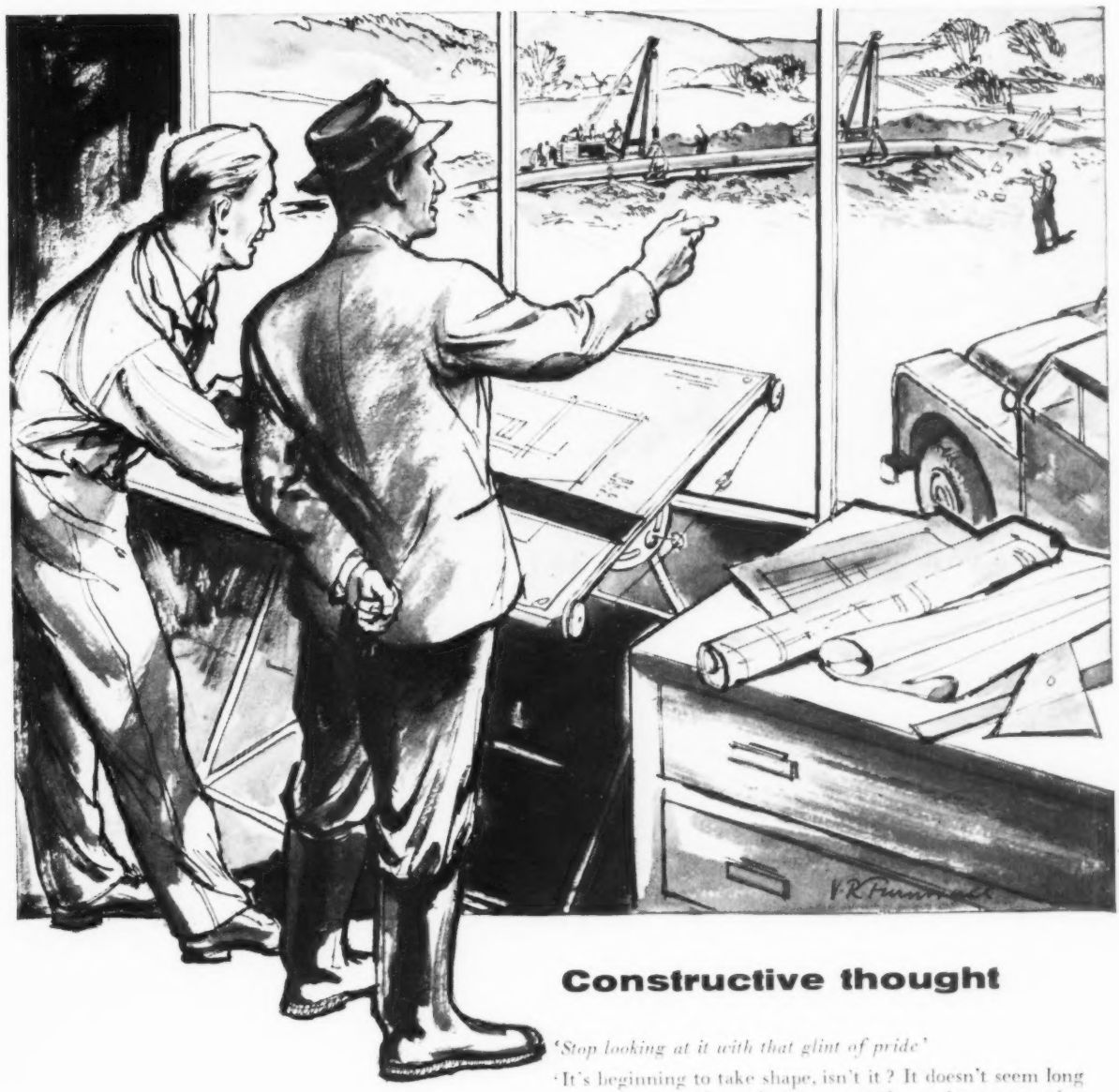

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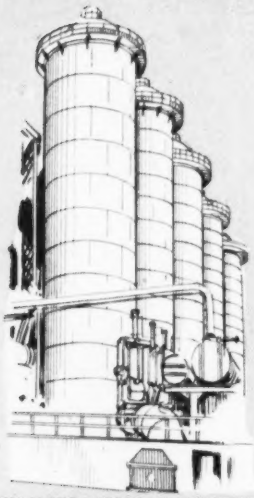

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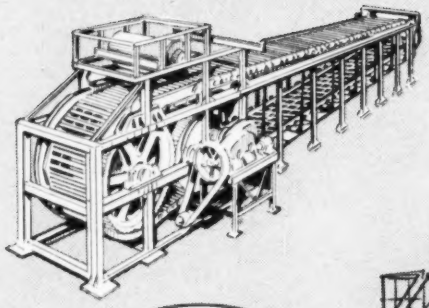

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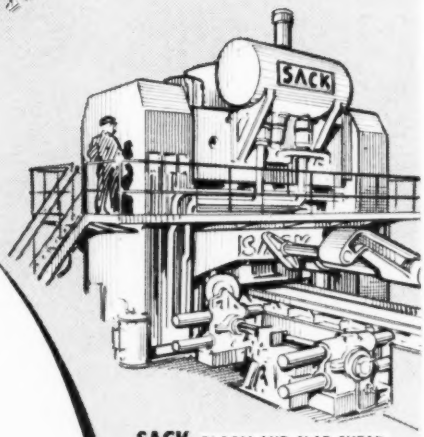

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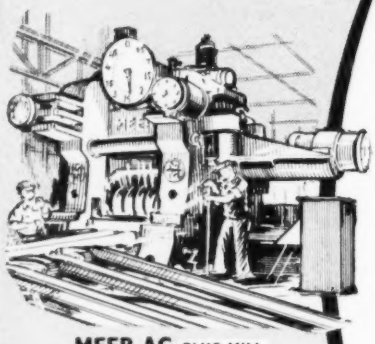

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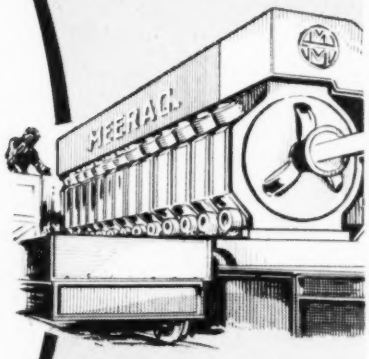

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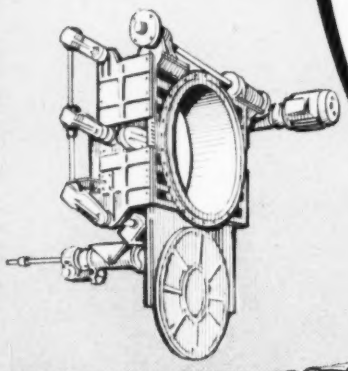

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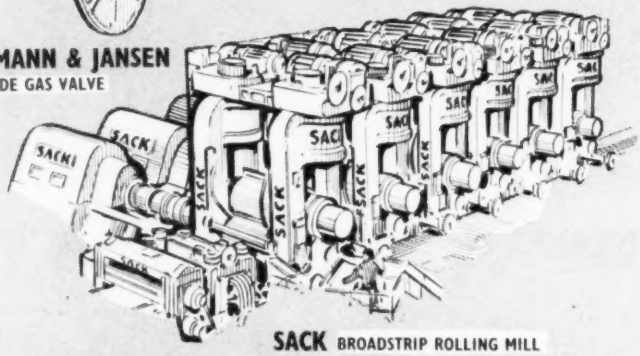

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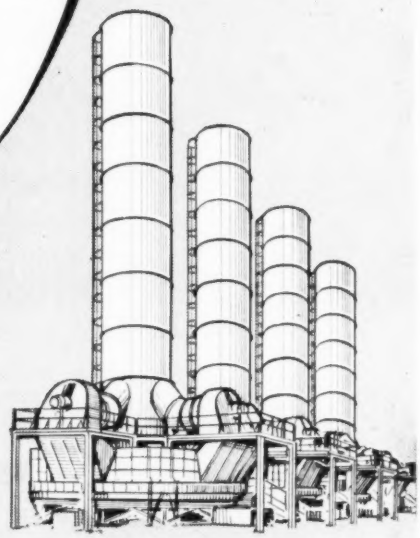

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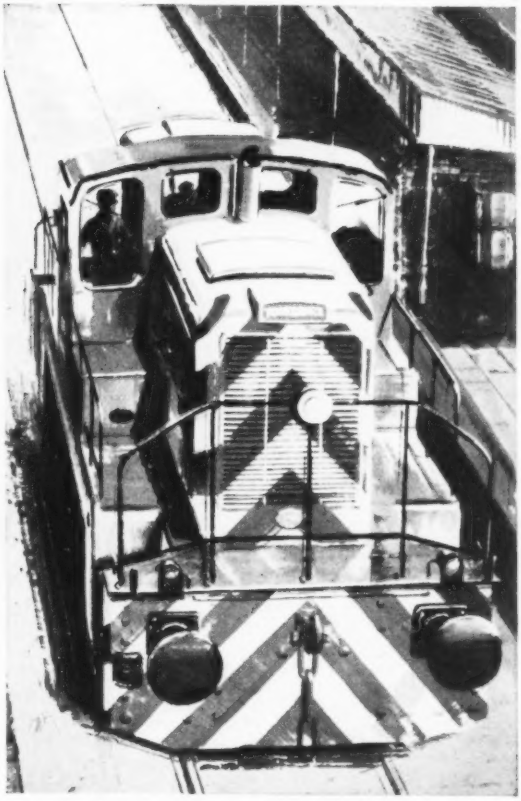
27 new diesel locomotives for the PLA



The Port of London Authority has recently bought 27 diesel locomotives from the Yorkshire Engine Company.

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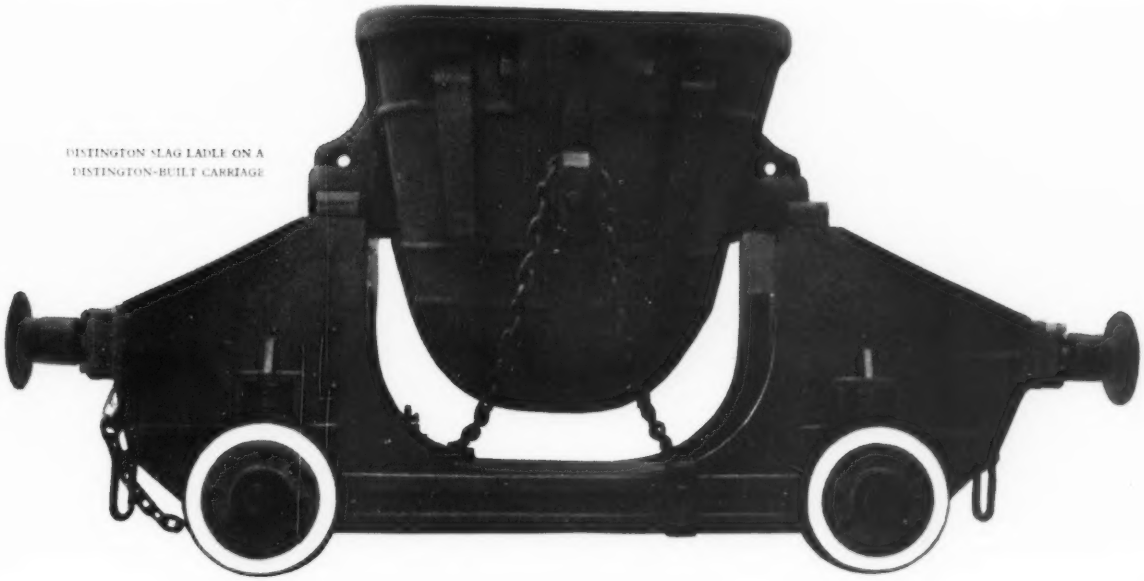

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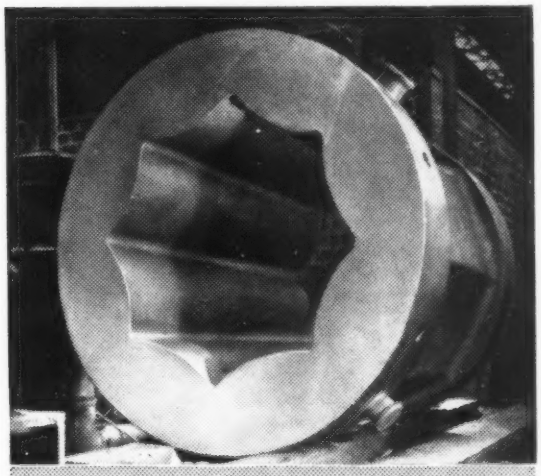

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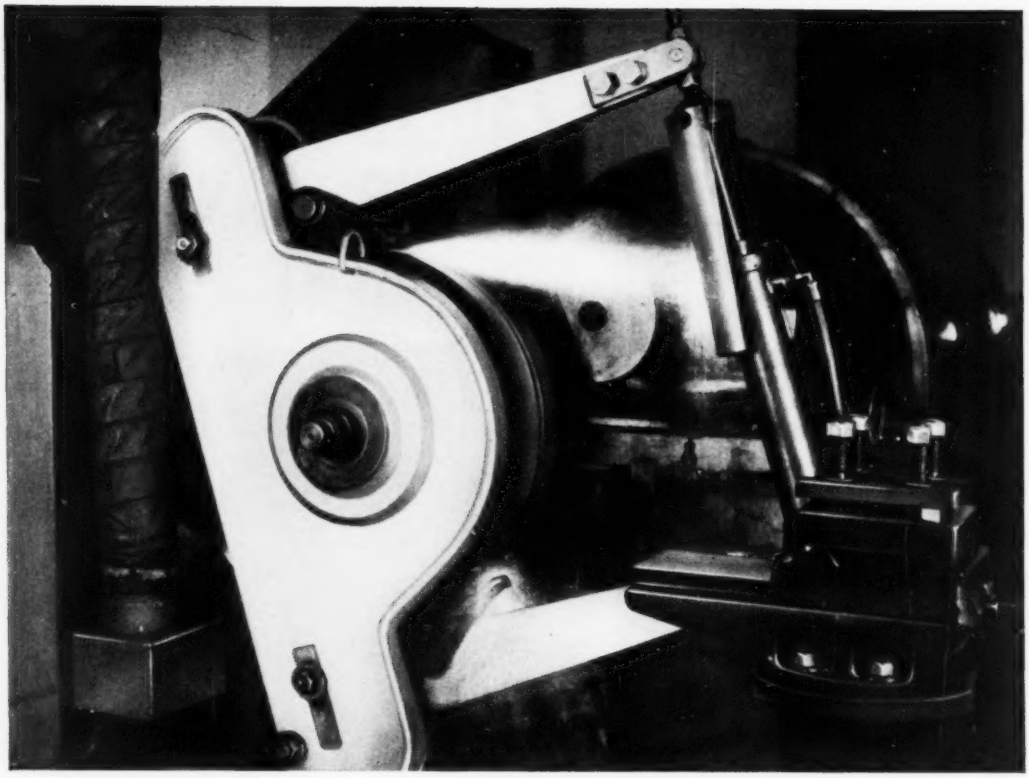

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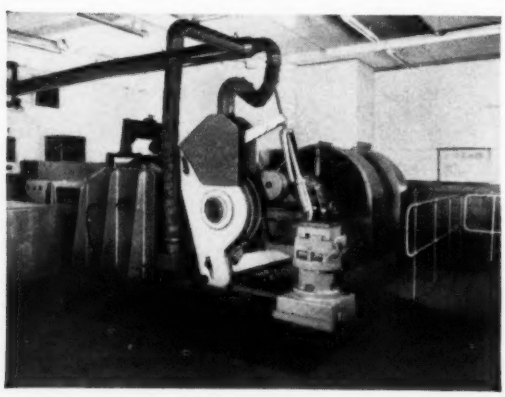

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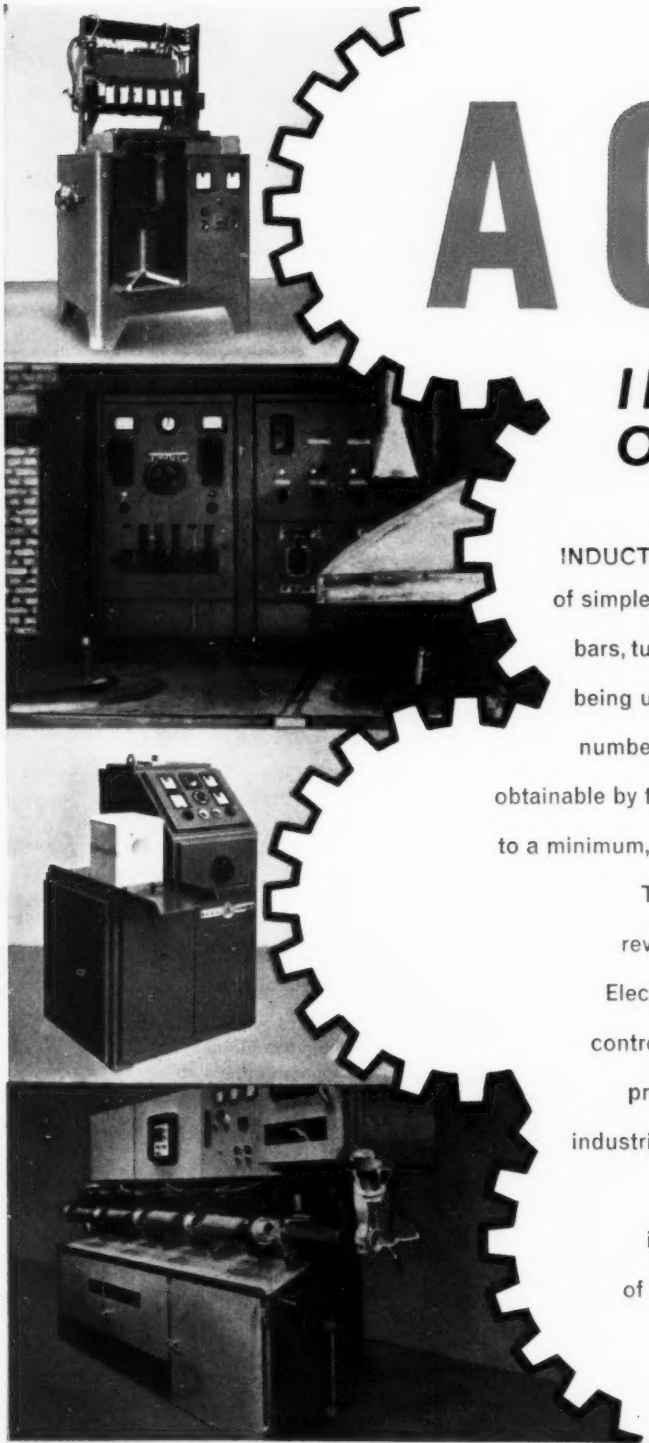

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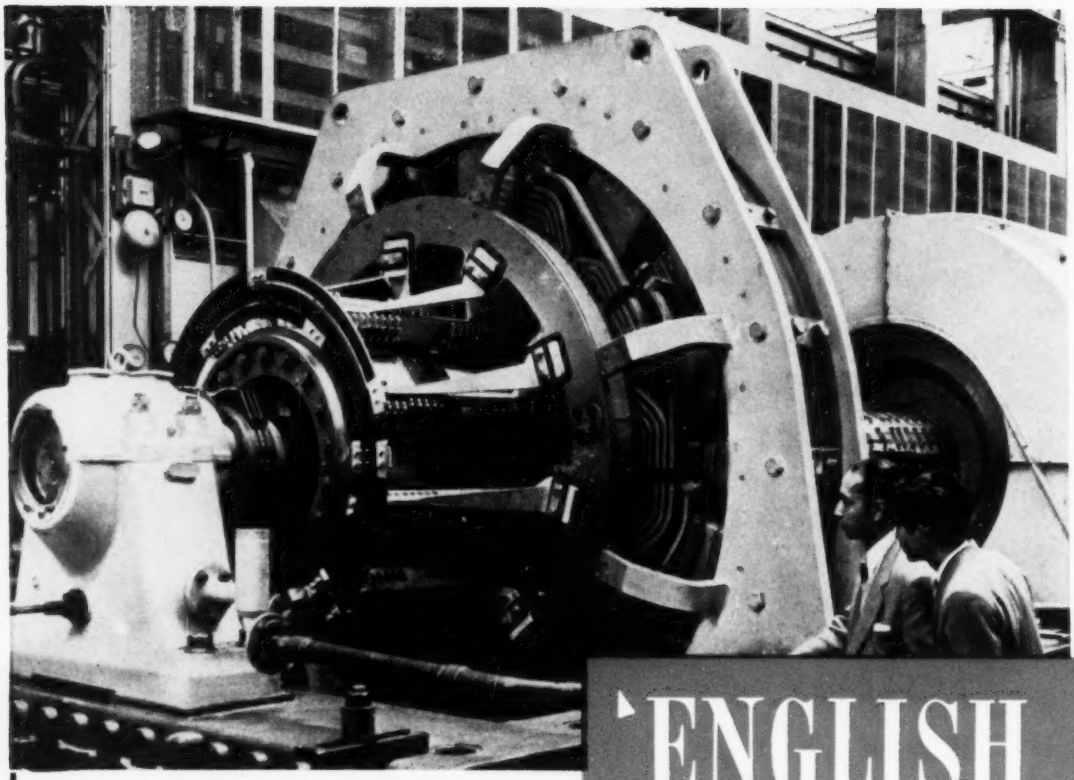

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puts power into steel

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'ENGLISH ELECTRIC'—one of the members of the ISCON Electrical Group—has supplied to the Durgapur Steelworks all the electrical equipment for a 32" intermediate blooming mill and a continuous billet mill, and also a large number of auxiliary motors for all parts of the works.

INTERMEDIATE BLOOMING MILL

4,500 h.p. (r.m.s.). 80/120 r.p.m. main drive supplied from two generators driven by a 6,000 h.p. synchronous motor.

CONTINUOUS BILLET MILL

Five main drives totalling 10,600 h.p. (r.m.s.).

MILL AUXILIARY DRIVES

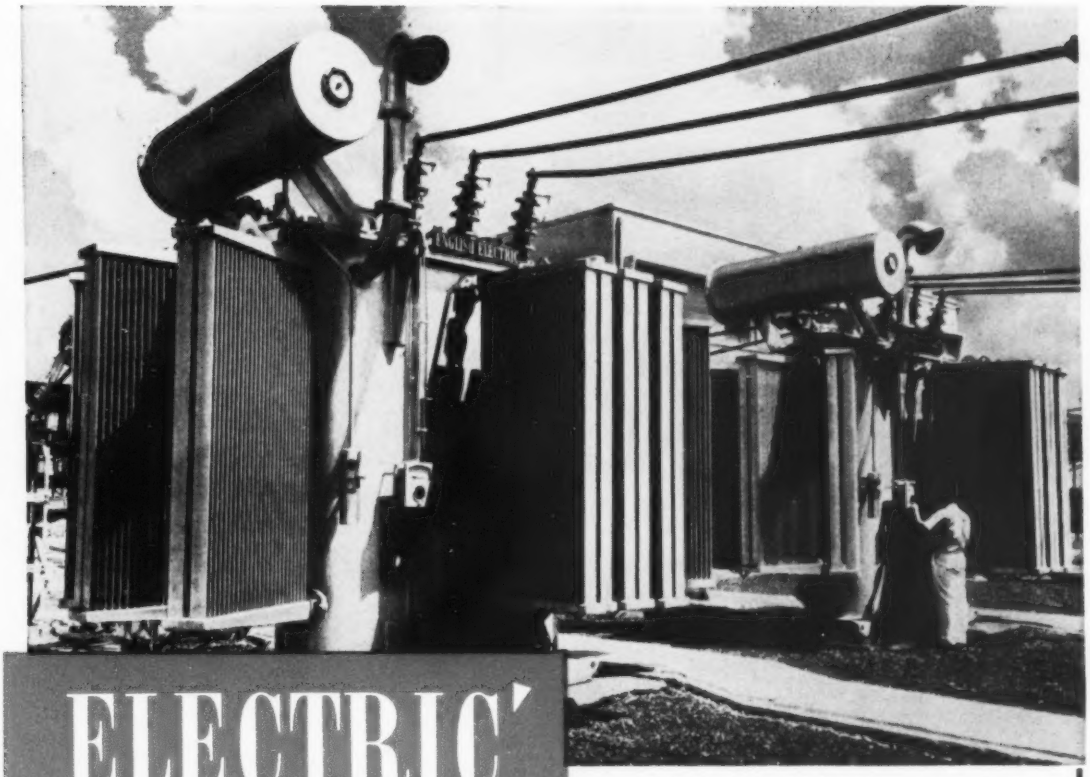
Over 2,500 h.p. (r.m.s.) of Ward Leonard controlled drives, and 7,000 h.p. (r.m.s.) constant voltage drives for the intermediate and billet mills.

WORKS AUXILIARY MOTORS

Numerous auxiliary motors ranging from ¼ h.p. to 1,600 h.p.

THE ENGLISH ELECTRIC COMPANY LIMITED, MARCONI HOUSE, STRAND, LONDON, W.C.2.

MT. 56



ELECTRIC'

Two of the five 33/11 kV 10MVA power transformers at Punabad.

making at Durgapur

DISTRIBUTION EQUIPMENT

The Company also supplied the majority of the distribution equipment for the thirty-two substations in the complete steelworks, and the mechanical parts for thirteen 500 h.p. diesel-electric locomotives for use within the works.

TRANSFORMERS
42 transformers from 250 kVA to 10 MVA.

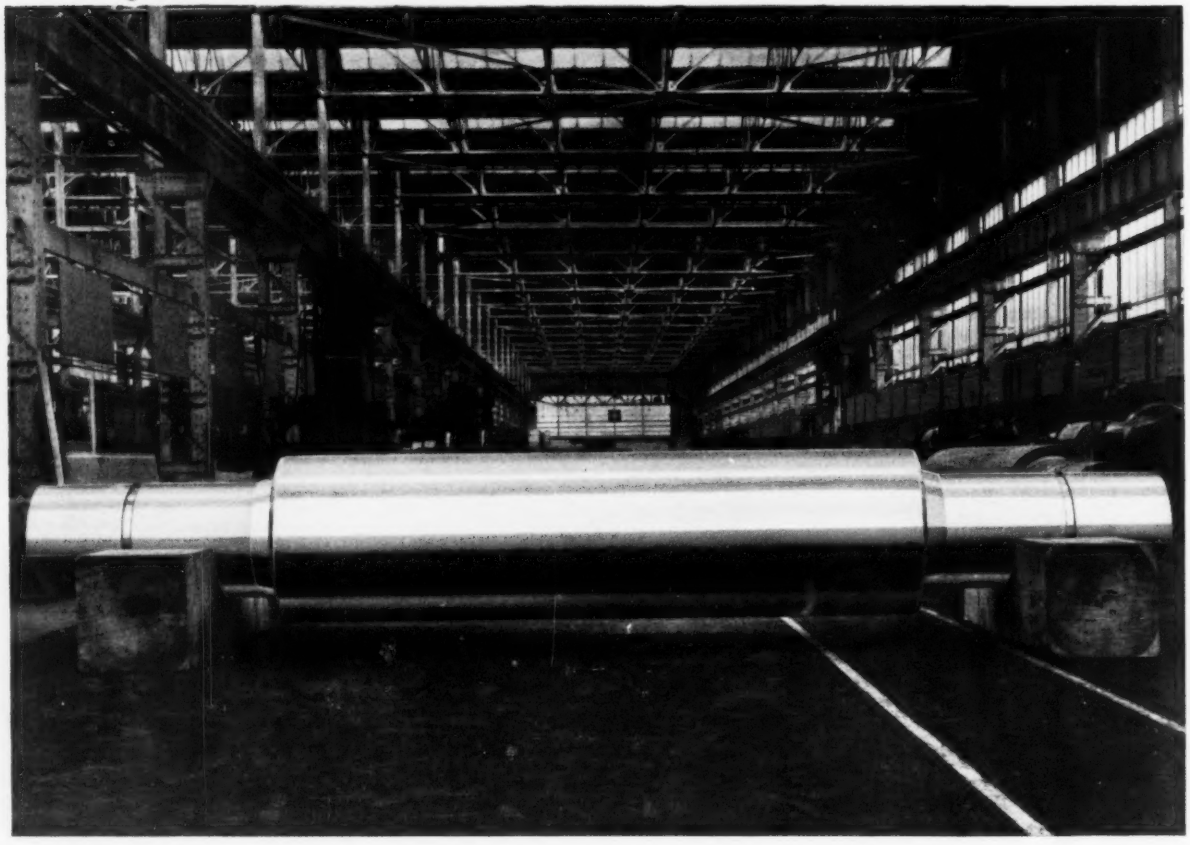
RECTIFIERS
17 equipments from 250 kW to 1,000 kW.

SWITCHGEAR
34 switchboards, 400 V and 11 kV.

FUSEGEAR
125 combination fuse-switchboards.

Metal Industries Division, Stafford. WORKS: STAFFORD · PRESTON · RUGBY · BRADFORD · LIVERPOOL · ACCRINGTON

CRAFTSMANSHIP BY THE TON



This heavyweight turned the scales at 28 tons, 10¼ cwts. It is a Duplex Manganite Alloy Indefinite Chill Work Roll, 39″ × 150″ × 266″, for a 4 High Plate Mill. From this, to the smallest work roll, you can rely on us for accuracy and quality.

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BRC 34

HOLSET

CHOSEN BY
THE UNITED STEEL COMPANIES LIMITED

FLEXIBLE RUBBER BLOCK COUPLINGS

Appleby-Frodingham Steel Company
Samuel Fox & Company Limited
Steel Peech & Tozer
Workington Iron & Steel Company

CHARACTERISTICS OF HOLSET COUPLINGS

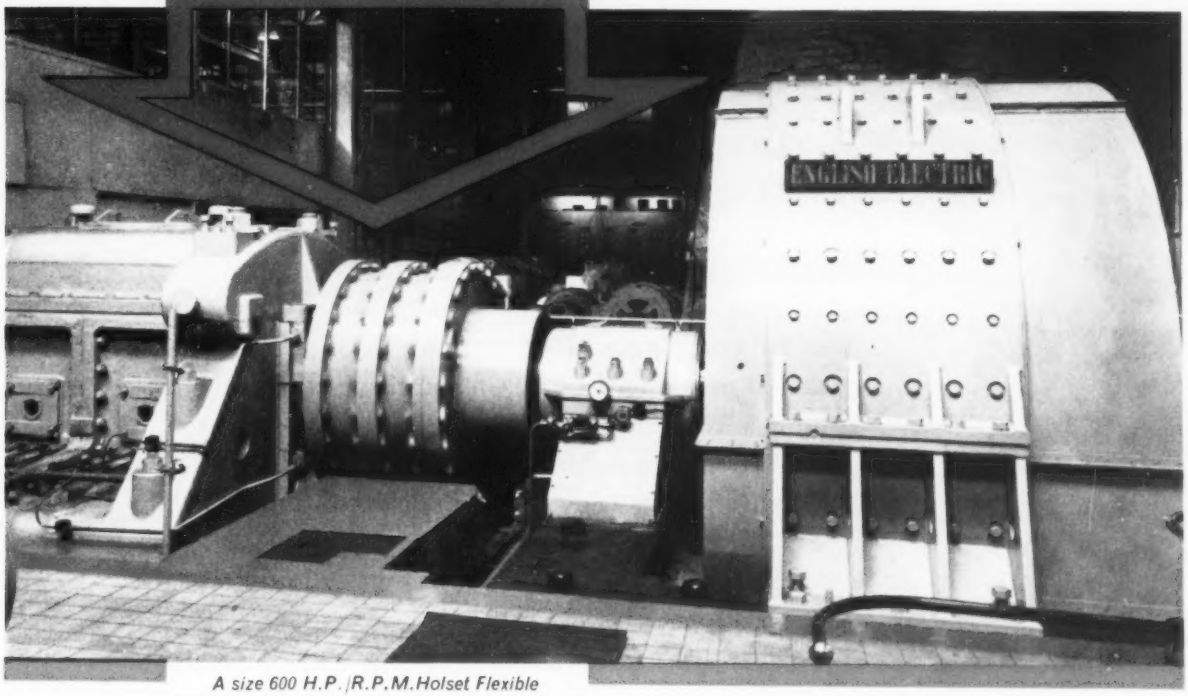
Can accommodate limited angular and parallel misalignment.

Absorb shocks and operate noiselessly under any conditions.

The multi-row arrangement of the blocks results in a small diameter and, therefore, a lower WR^2 value than any other torsionally resilient coupling.

No end thrust on the bearings of the connected shafts.

No lubrication or maintenance required.



A size 600 H.P./R.P.M. Holset Flexible Rubber Block Coupling installed on the 40" Slabbing Mill at the Stocksbridge Works of Messrs. Samuel Fox & Company Limited

THE **HOLSET**
ENGINEERING CO. LTD
TURNBRIDGE, HUDDERSFIELD.
TELEPHONE HUDDERSFIELD 7480
TELEGRAMS HOLSET, HUDDERSFIELD

Ore handling . . .

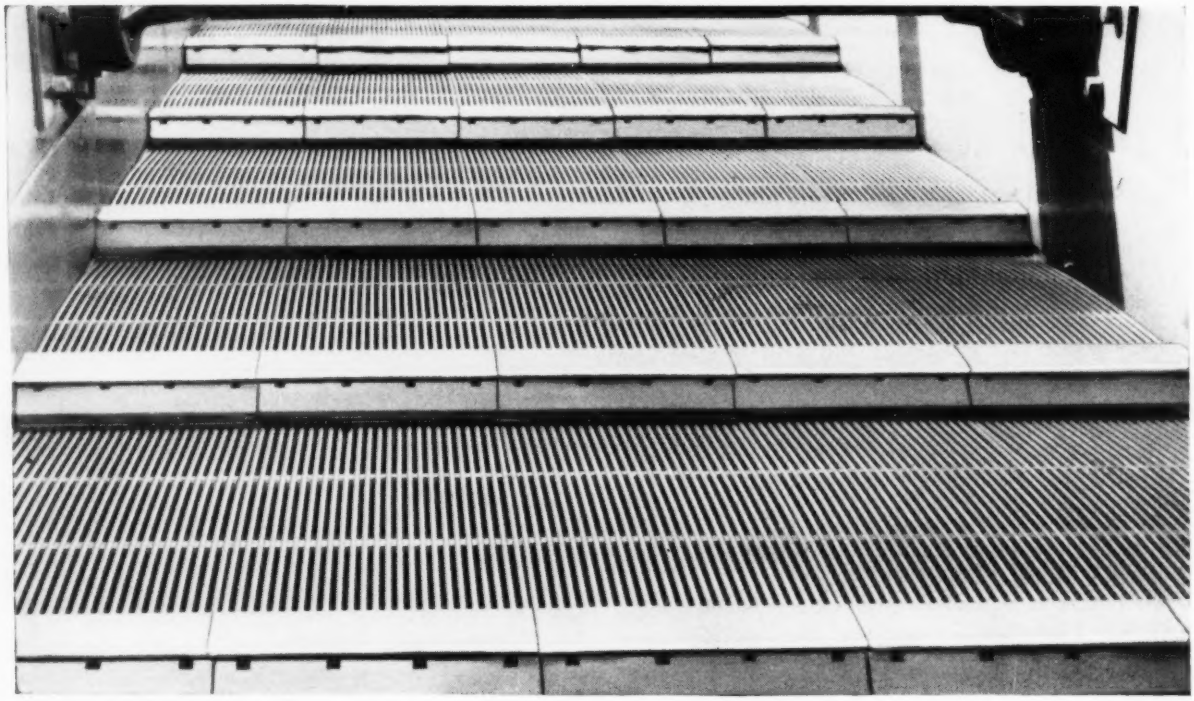


Illustration shows a typical Ty-rock Rod Deck Screen.

WITH THE Ty-rock ROD DECK SCREEN

The TY-ROCK ROD DECK SCREEN is a recent addition to the range of International Combustion equipment for ore handling. The efficiency of this screen has been proved in operation and particularly satisfactory results are being achieved with ores known to be difficult to handle.

For further details of the Rod Deck Screen and complete mechanical handling plants, please write to:

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INTERNATIONAL COMBUSTION PRODUCTS LIMITED

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Member of Atomic Power Constructions Limited — One of the British Nuclear Energy Groups

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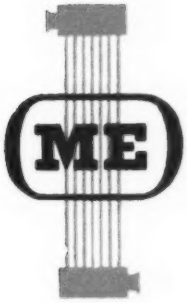

M.E./SCHACK COMBINED CONCENTRIC RECUPERATORS FOR SOAKING PITS GIVE AIR PREHEATS OF 800°C WITHOUT DILUTION AIR

★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★

Twenty combined concentric recuperators together with twenty gas recuperators– to be in commission by September, 1961–have been ordered by Messrs. Priest Furnaces Limited for fitting to blast furnace gas fired soaking pits at the New Spencer Works of Messrs. Richard Thomas & Baldwins Limited.

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CONSULTING & MANUFACTURING ENGINEERS

INDUSTRIAL HEATING EQUIP

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SALEM-BROSIUS, INC.
is pleased to announce
receipt of an order for the design and erection of:-

Four 250 ton capacity
Pusher Type Slab Re-heating Furnaces
for installation at the works of GREAT LAKES STEEL CORPORATION
Subsidiary of National Steel Corporation

These furnaces will have
five heating zones (three over firing and two under
firing) and will be equipped with induced draught stacks and
metallic recuperators for air pre-heating.
Material to be heated is carbon steel stock
30ft. long, 20" - 76" wide and from 6¼" - 12" thick, heating from cold
to 1300°C at the rate of 250 tons per hour. The furnaces
will have fully automatic control for temperature,
pressure and combustion, and in addition closed circuit television
in order to keep the operator fully informed.

For the latest designs in slab reheating furnaces, consult

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ADAMSON-ALLIANCE CO. LIMITED

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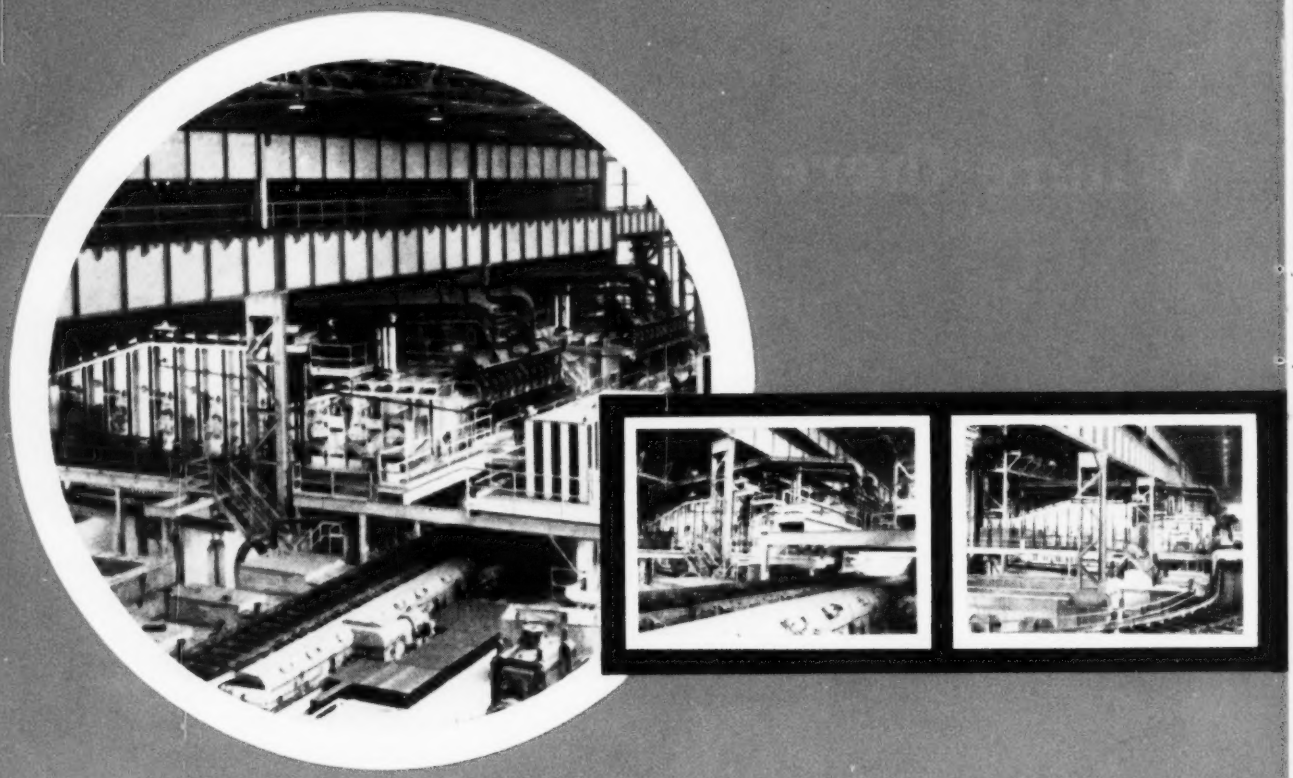


The largest

oil-fired slab reheating furnaces

in Europe

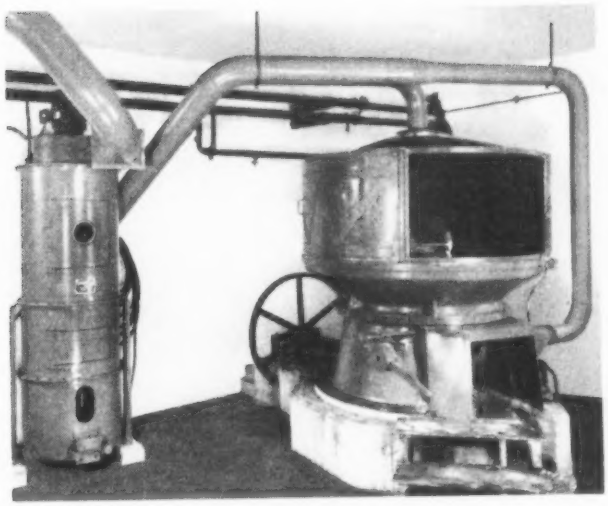
We have recently commissioned two new Slab Reheating Furnaces which form part of John Summer's Strip Mill extensions. These furnaces, the largest in Europe, have replaced the three S. & A. Slab Reheaters which have heated approximately 12 million tons of steel since their completion in 1939. All Britain's wide Strip Mills are served by S. & A. Continuous Furnaces.

Stein & Atkinson Ltd.

Westminster House, Kew Road, Richmond, Surrey

FURNACE ENGINEERS

HOW CAN YOU BEST HANDLE YOUR DUST?



Wet or dry? If wet, or when it is simpler and more advisable to dispose of "valueless" dust in sludge form, the VISCO-HANDTE Dust Collector is the most economical way of collecting dust from foundry knockouts, dressing, fettling, ore handling and subsidiary operations. It is manufactured and sold exclusively in the United Kingdom by VISCO. Enquiries are invited to

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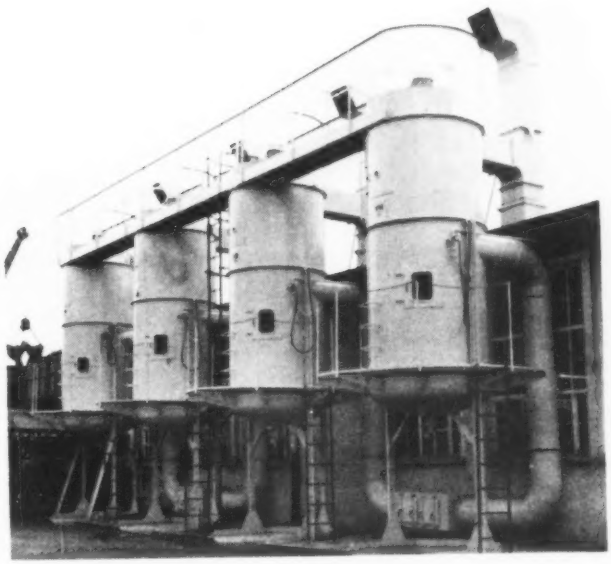
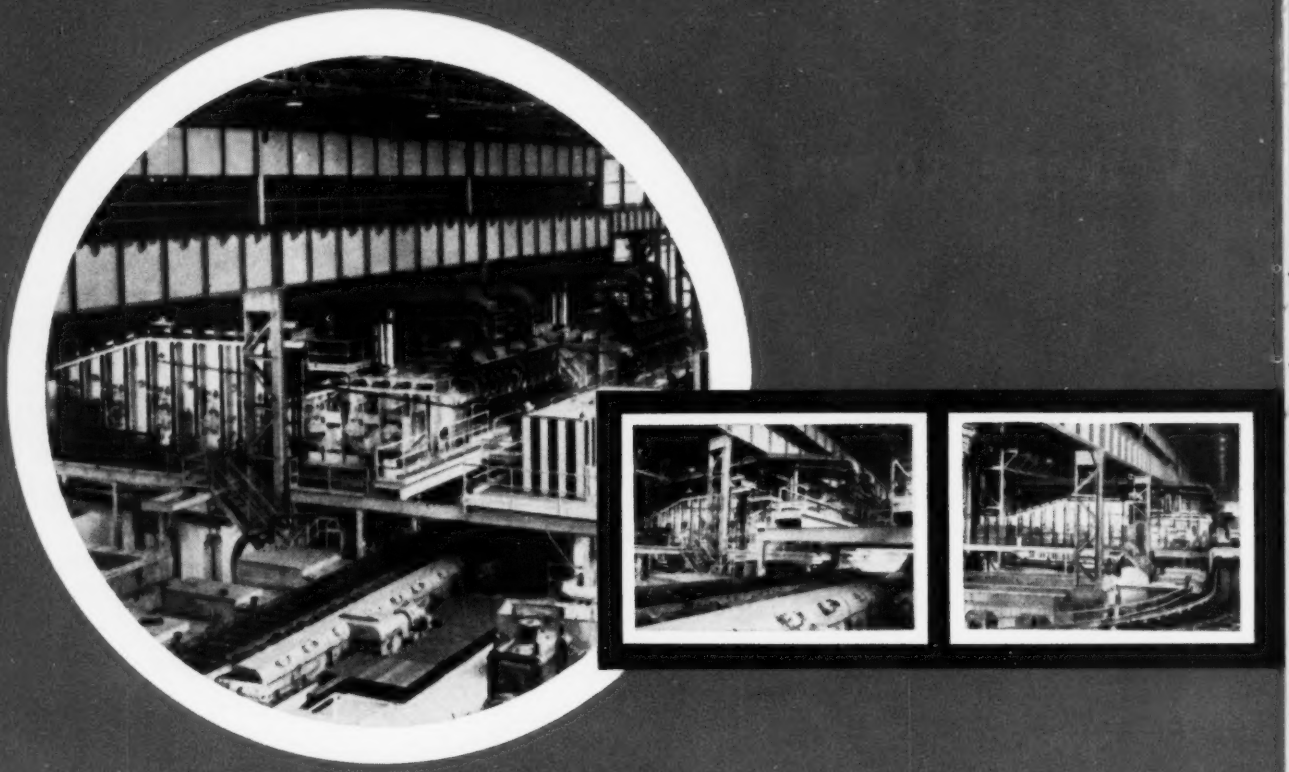


VISCO-HANDTE

Wet type Dust Collectors



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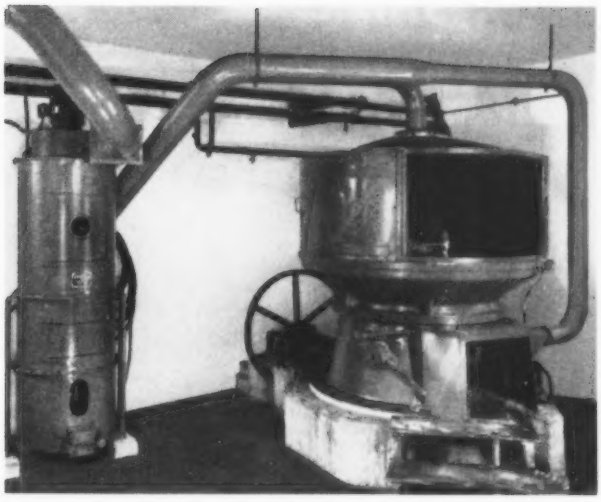

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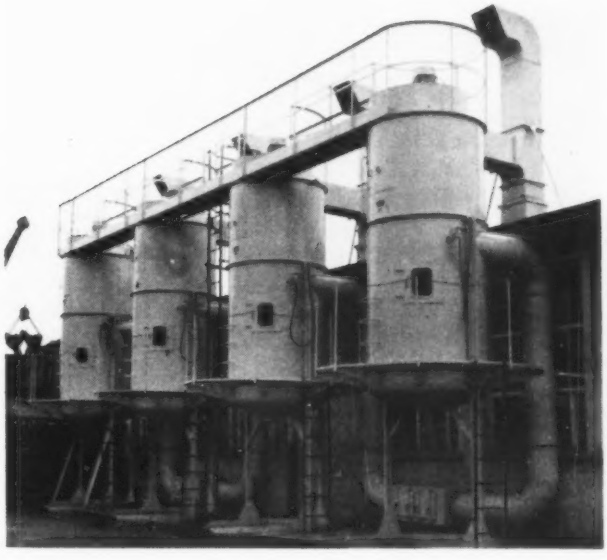
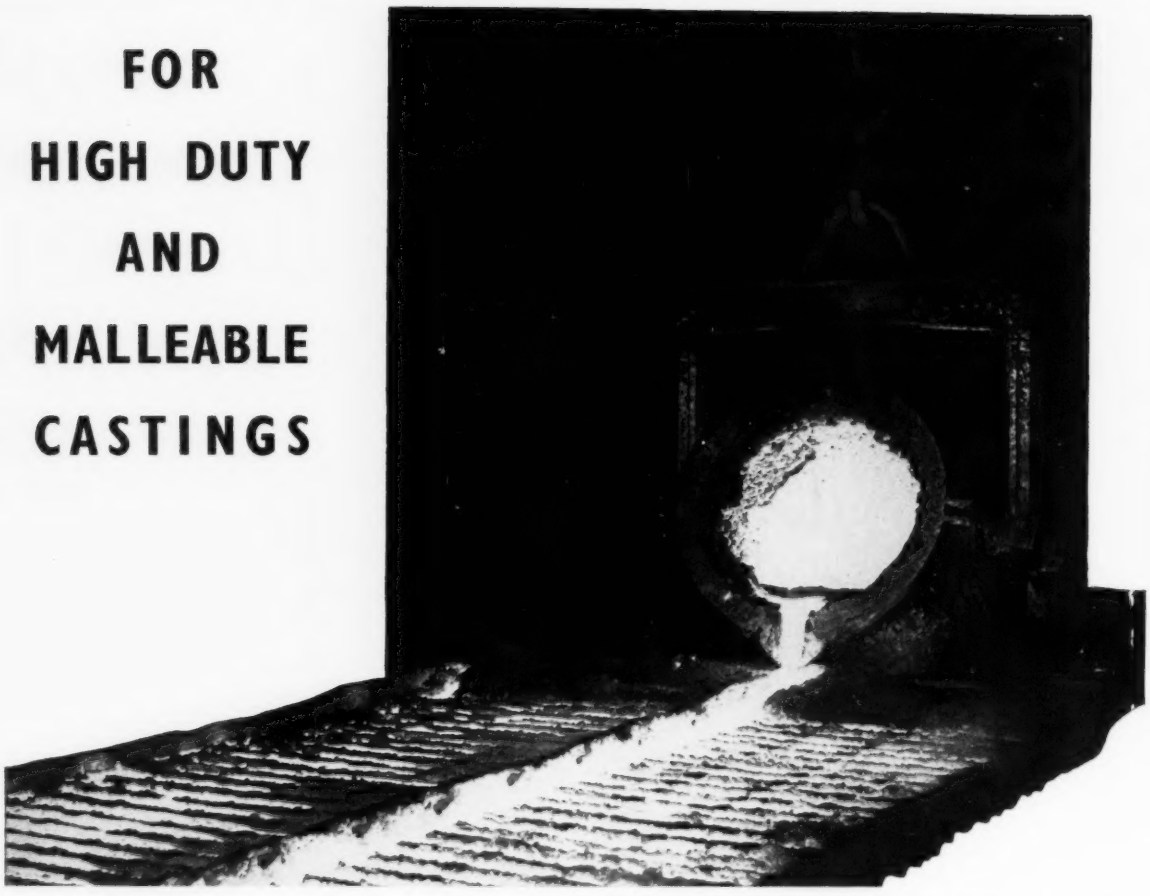


VISCO-HANDTE

Wet type Dust Collectors

FOR HIGH DUTY AND MALLEABLE CASTINGS



The seven standard grades of Stanton Dale Refined Pig Iron

GRADES:	A	B	C	D	E	F	G
SILICON%	1·9–2·1	1·4–1·6	0·9–1·1	2·25–2·5	0·9–1·1	1·4–1·6	1·9–2·1
SULPHUR%	0·06	0·07	0·08	0·05	0·08	0·07	0·06
PHOSPHORUS%	0·6–0·7	0·6–0·7	0·6–0·7	0·4–0·5	0·25	0·25	0·25
MANGANESE%	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5
TOTAL CARBON%	2·7–3·0				2·8–3·1		

In addition to the above other grades of Dale Refined Iron can be supplied to meet more exacting demands which call for alloy additions and special processing.

STANTON *Dale Refined* PIG IRON

THE STANTON IRONWORKS COMPANY LIMITED NEAR NOTTINGHAM

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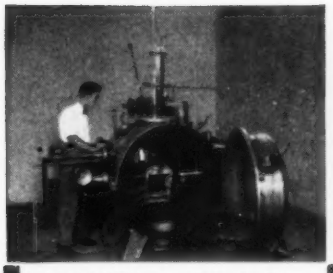
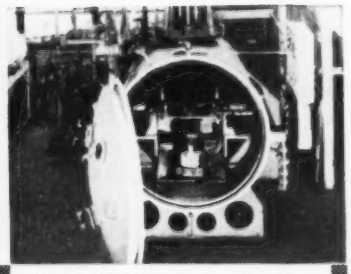


Model 2555 Vacuum Induction Furnace with melting capacity of 50 pounds of steel. Other standard furnaces have capacities of 12 to 3,000 pounds.



Model 2705 Non-Consumable Arc Skull Furnace with a capacity of 50 pounds of titanium. Other standard vacuum arc furnaces have capacities of 8 to 10,000 pounds of titanium.

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for all heat-treatment purposes

Metals for parts to withstand jet engine temperatures and stresses can be produced in vacuum furnaces. Such metals enable components to be made with fewer rejects. If your products need parts that operate under severe conditions or need high purity metals or alloys—a vacuum furnace will help you to produce them.

Wild-Barfield can supply equipment made to the designs of and tested by the unrivalled experience of the National Research Corporation who have built and operated more high vacuum furnaces than any other company in the world.

Write for details of the Wild-Barfield—NRC range of high vacuum plant.

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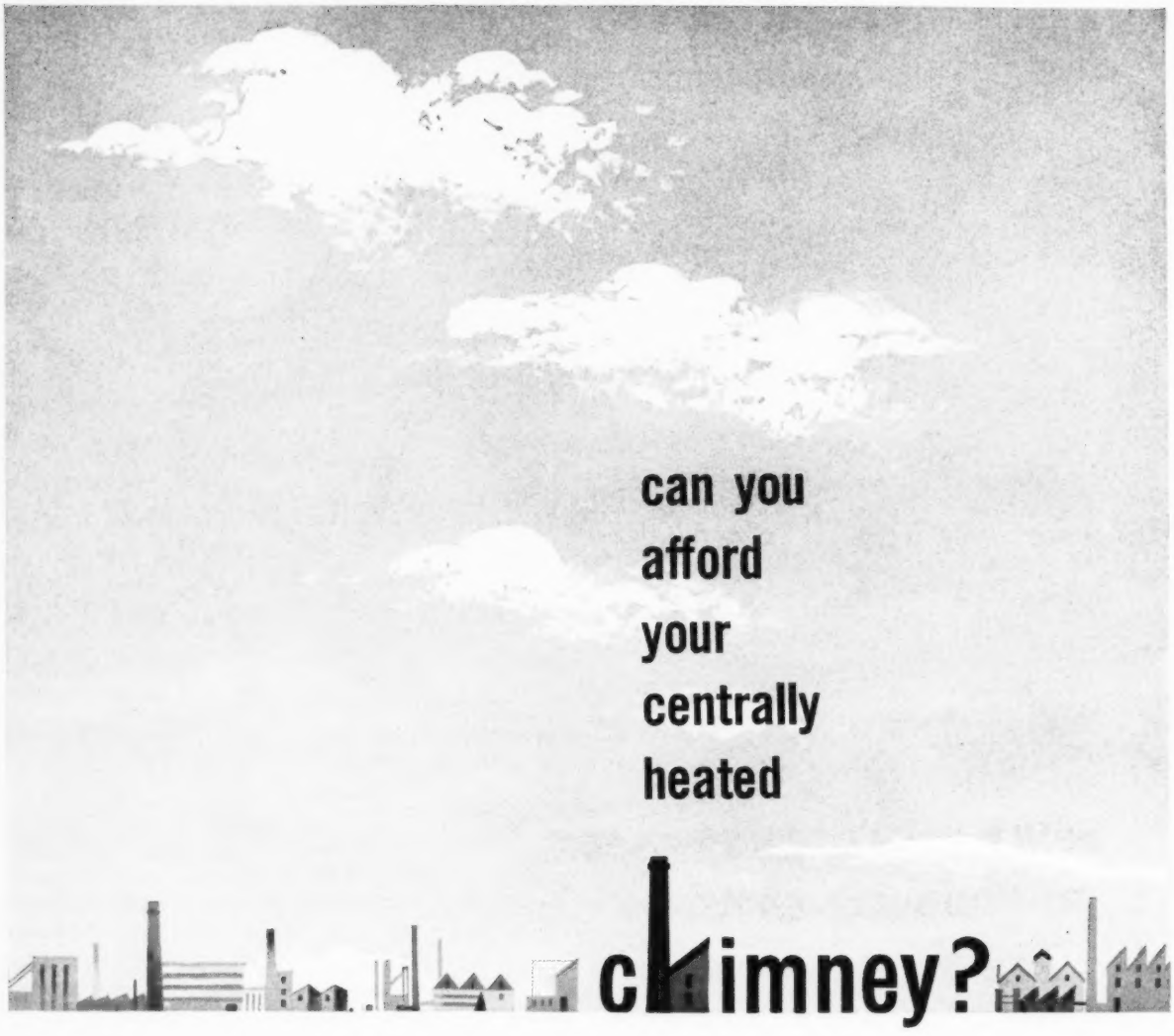

With rising production costs it's hardly likely. The people to see are Spencer-Bonecourt-Clarkson who for over forty years have been experts in waste heat recovery for steam raising in a wide range of industries. In addition to fire-tube boilers, *S-B-C now also supply water-tube boilers.*

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S-B-C are the people best equipped to advise you and to act for you in the recovery of waste heat. Write or 'phone today — time spent now can save you pounds for years to come.

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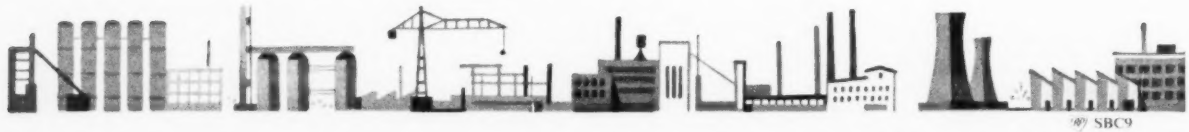

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THE NOURISHING GAS

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OXYGEN IS THE NOURISHING GAS.

To steelmakers in Britain and elsewhere, benefiting from the introduction of new oxygen steelmaking processes, the name couldn't be more apt. Oxygen is being increasingly used in the iron and steel industry. A converter furnace, employing oxygen for the blast instead of air, not only makes steel quicker than any other furnace, it produces steel of improved quality as well. Use of oxygen also enables the design of converter furnaces of much greater capacity, which means an installation of lower cost for any given output tonnage. Similar benefits accrue with any other steelmaking furnace. Faster production, better quality, reduced capital costs—strong nourishment in any language.

The design, engineering and supply of oxygen steelmaking plant up to complete melting shops is the main concern of Davy United's Steel Processes Division. In support of these services, the Division offers metallurgical, technical and economic surveys to help any company planning a new steelmaking development.

DAVY-UNITED

STEEL PROCESSES DIVISION

SHEFFIELD, ENGLAND

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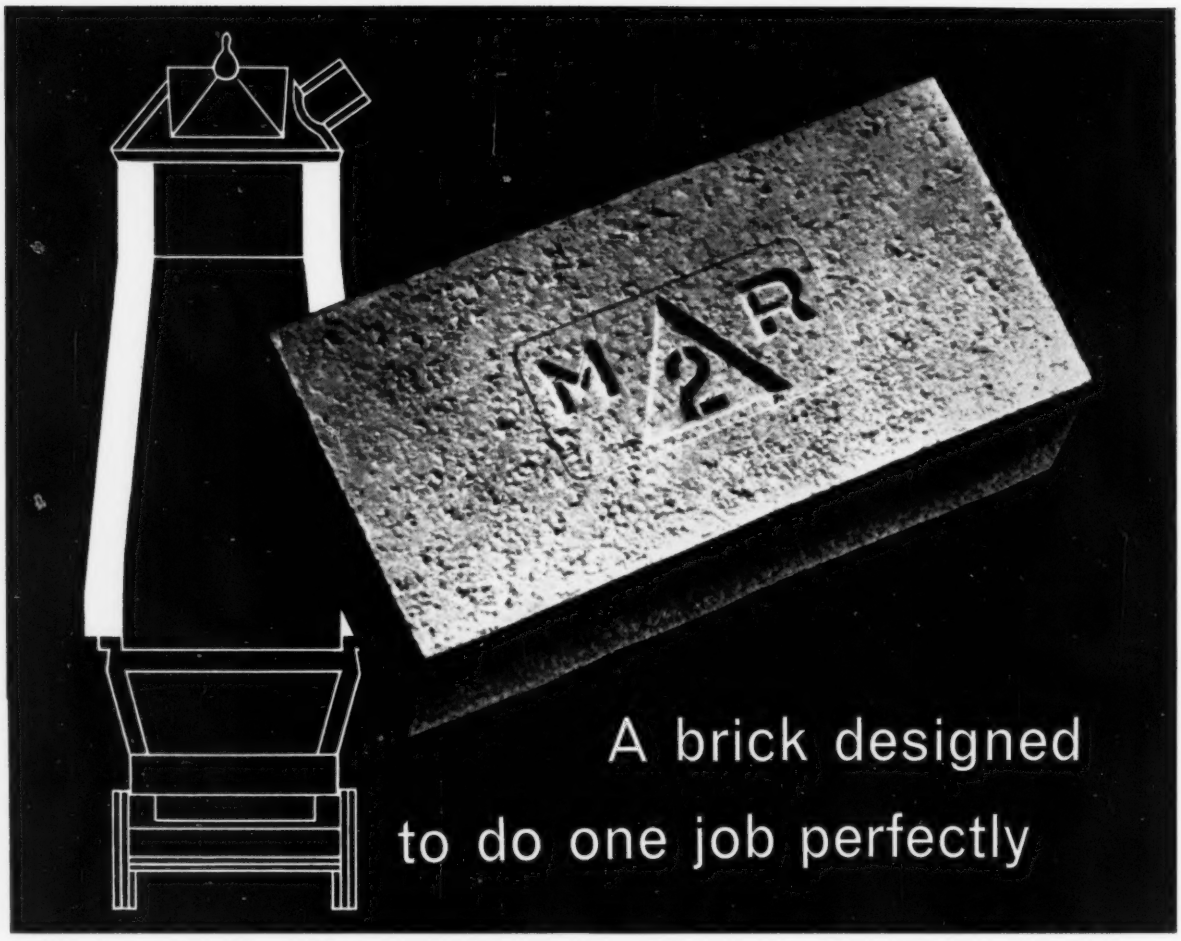

This is the M.R.2 Blast Furnace refractory – a very special brick indeed. It was developed for one application – the lining of Blast Furnaces operating on lean ores – with 100% sinter – and driven hard. M.R.2 is an extremely hard, low porosity refractory to enable it to resist the abrasive effect of the sinter. It is completely unaffected by carbon monoxide and is manufactured from very carefully selected raw materials prepared and moulded under the most stringent control with a final kilning at temperatures of the order of 1600°C to ensure complete volume stability at normal Blast Furnace operating temperatures. This is a brick with a narrow market, but it is typical of the way the Chemists, Physicists and Engineers at Neston look upon the making of refractories – as a branch of precise chemical engineering. Amongst the other things they make with equal care are M.R.1 and M.R.60 bricks and special shapes; low-heat storage insulating refractories M.I.28, and the whole range of Tri-Mor Mouldables and Castables for Monolithic linings which are having such a profound effect on all classes of furnace design.

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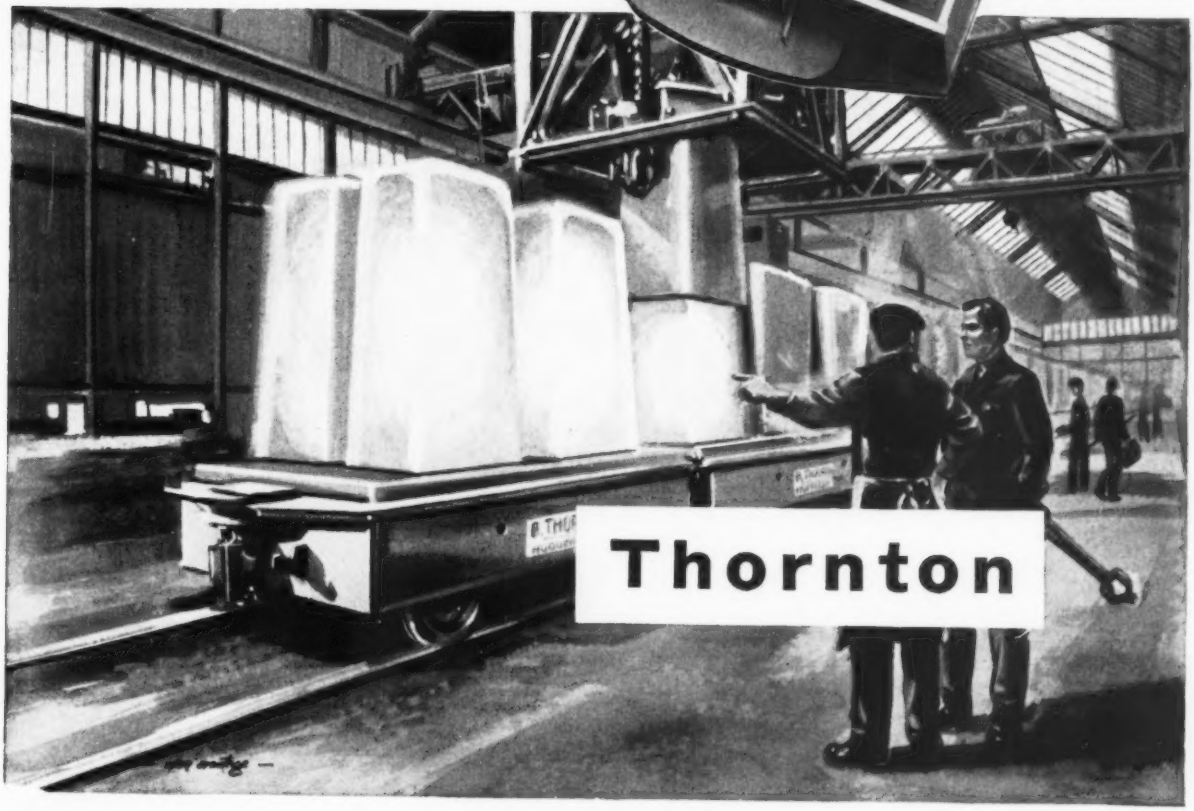
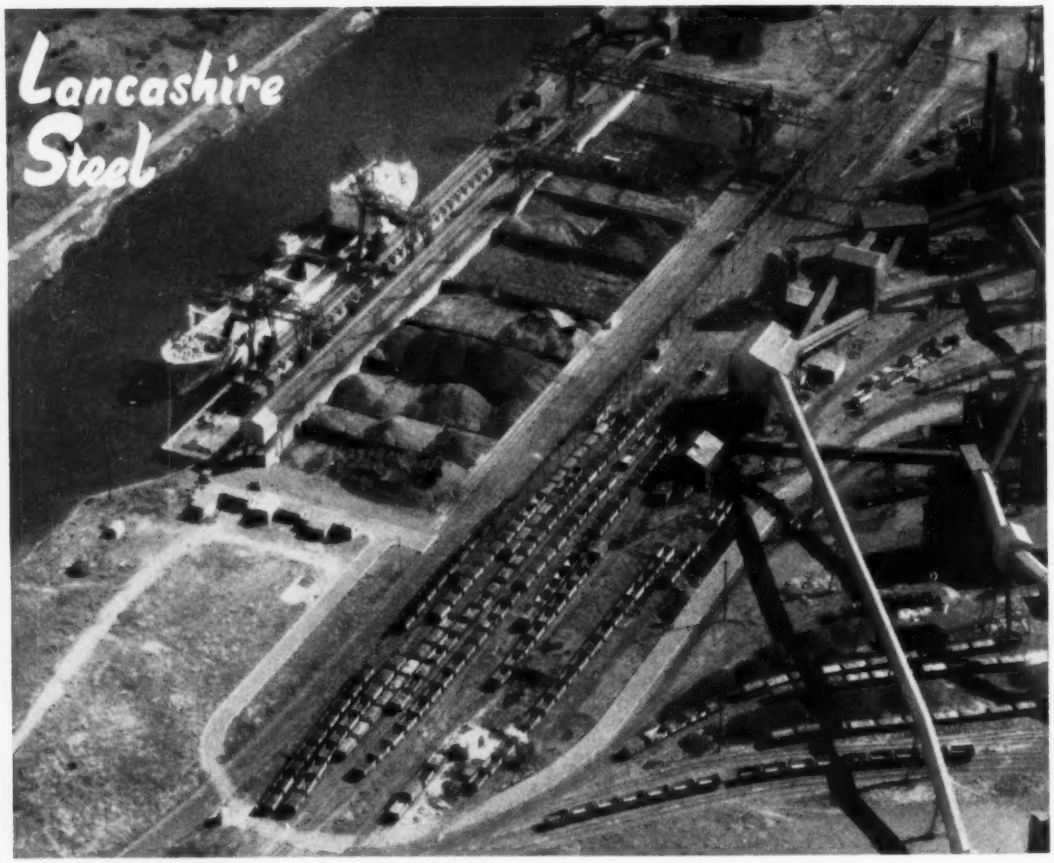
We shall be glad to quote against your requirements and specifications



B. Thornton Limited, Turnbridge, Huddersfield. Telephone 7541



AERIAL VIEW OF THE UNLOADING WHARF—*Photograph by Aero Pictorial Ltd.*

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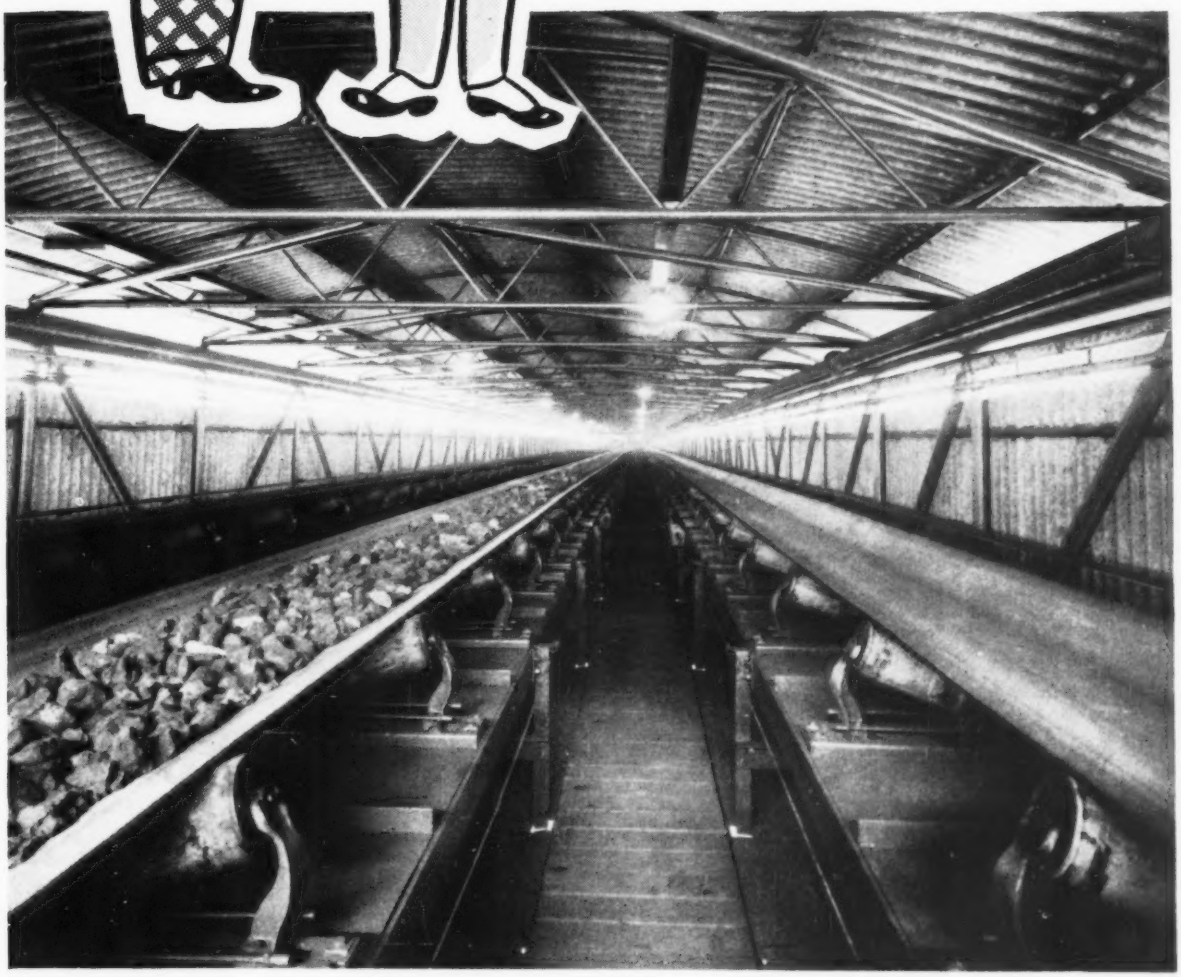
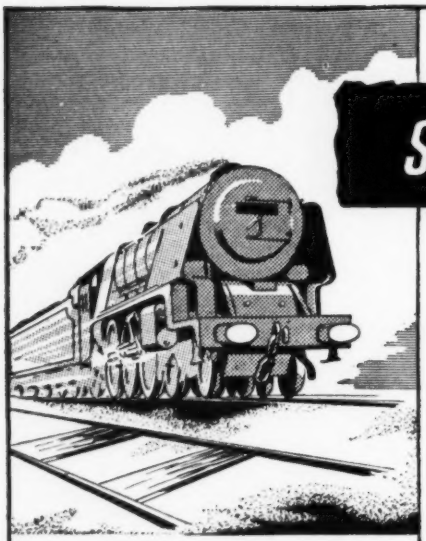
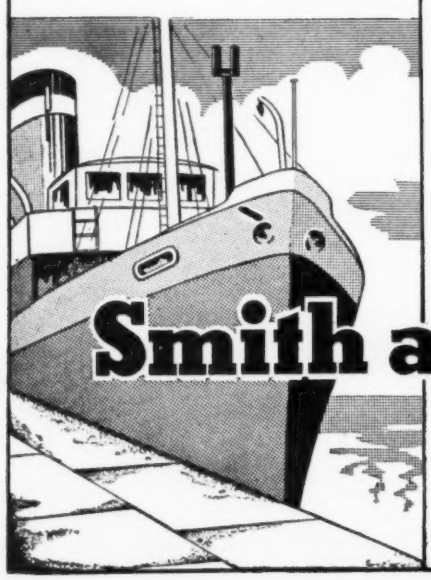
A hot tip . . .

If you have anything to move, remove, go, lift, shift, hoist, carry, winch, convey, elevate, lower, push, pull, roll, crush, screen, feed, transfer, transport, go round or circumnavigate—economically and effortlessly, long distance or short, consult

MOXEY
BIRMINGHAM ROAD
WEST BROMWICH







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* Metal Spraying by the most up-to-date methods done in our works or "in situ".

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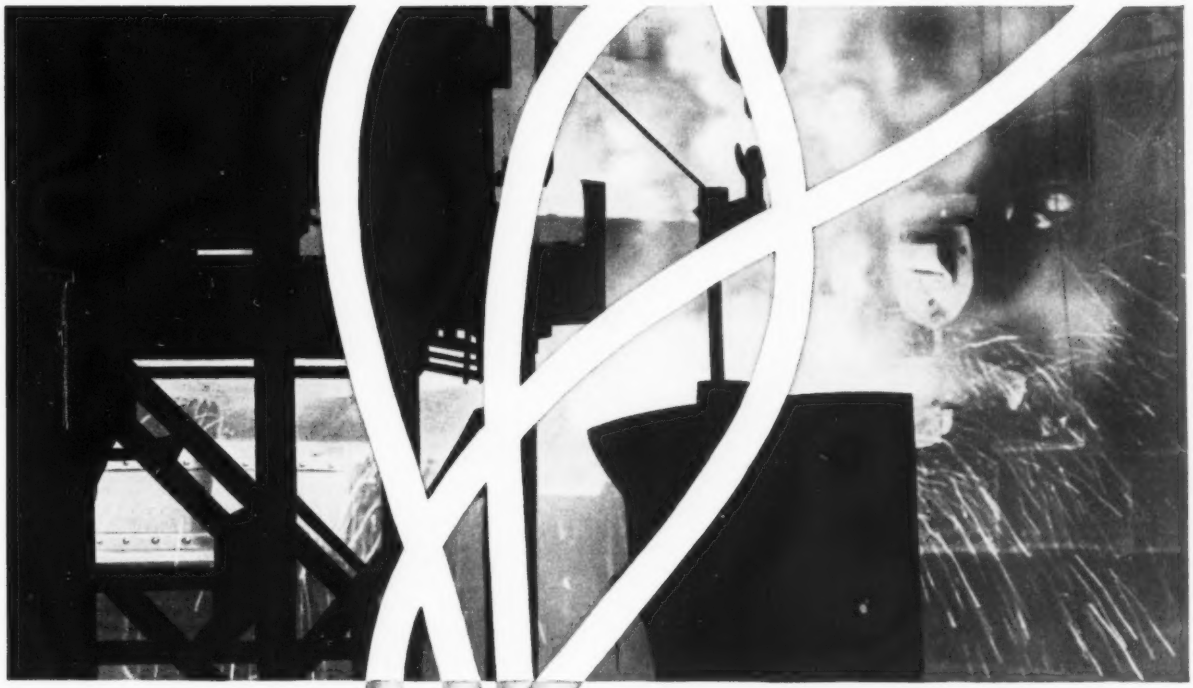

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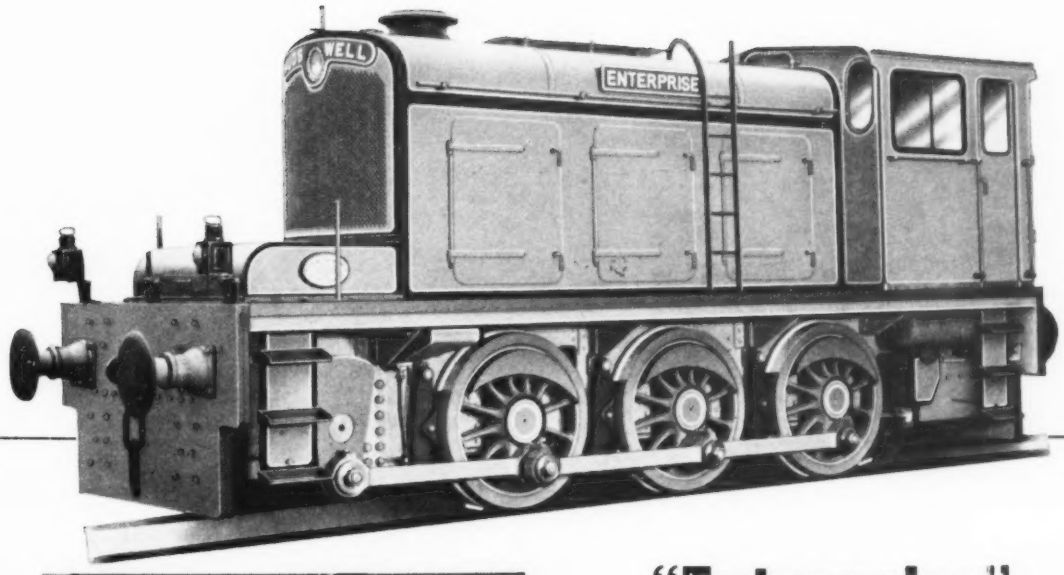

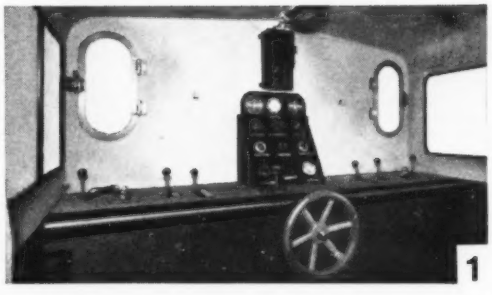
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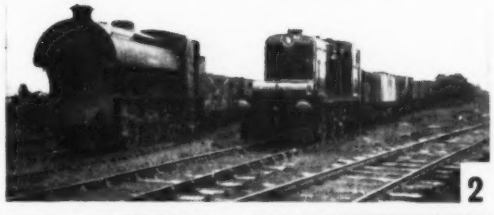
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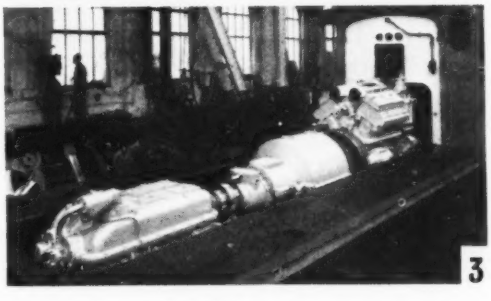
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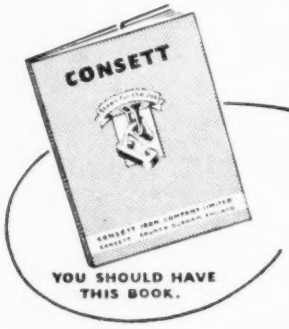

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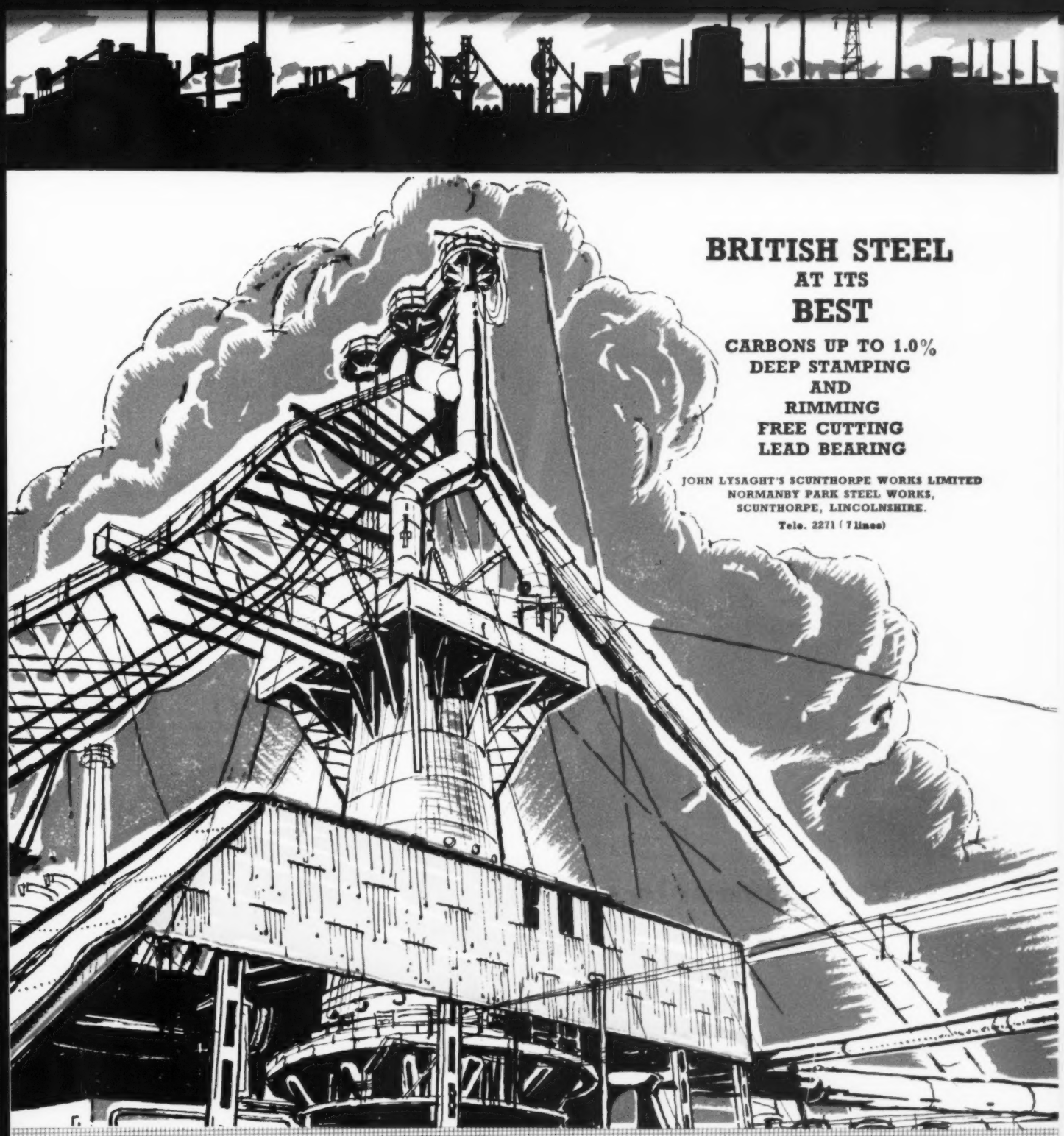

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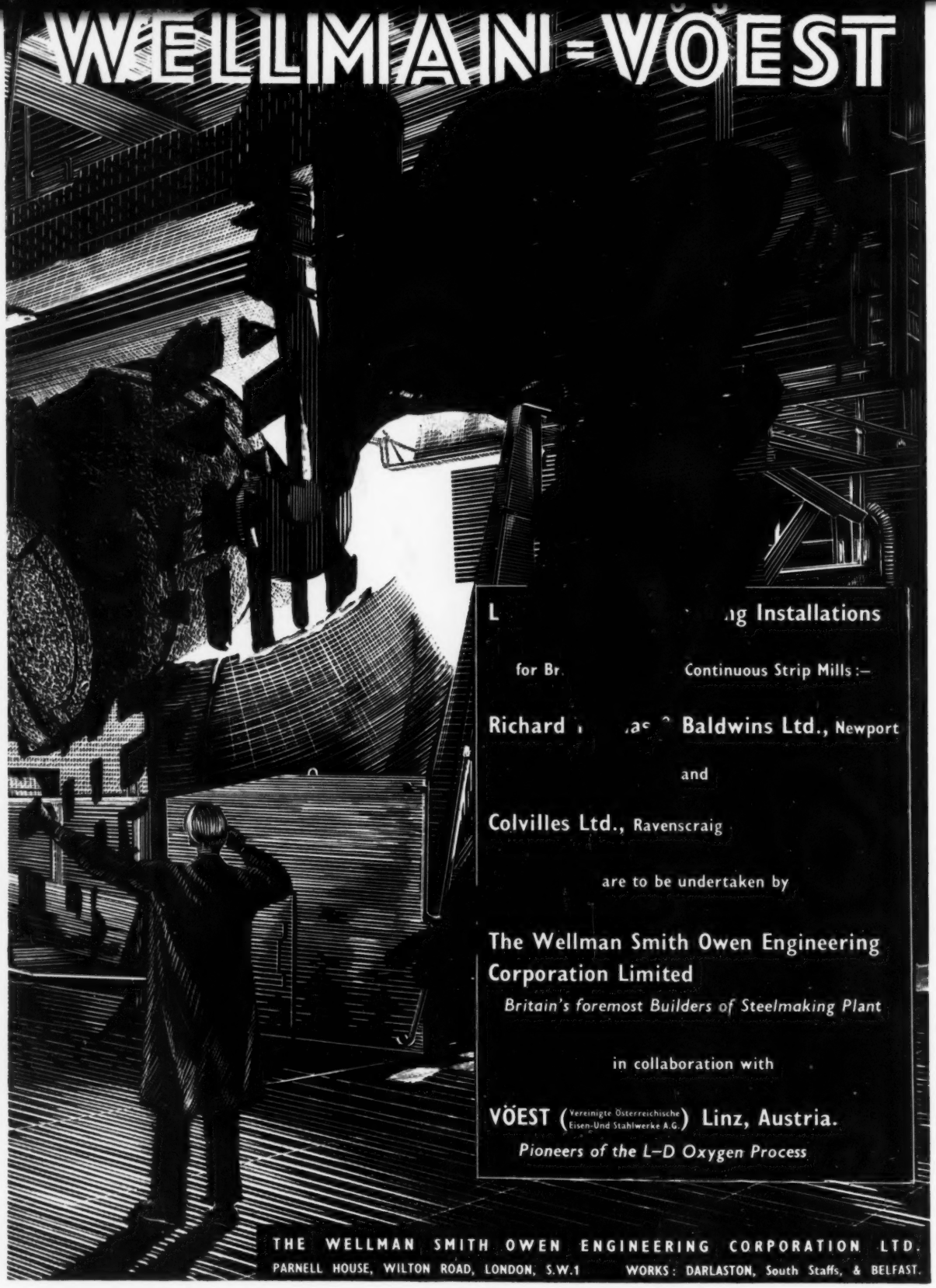

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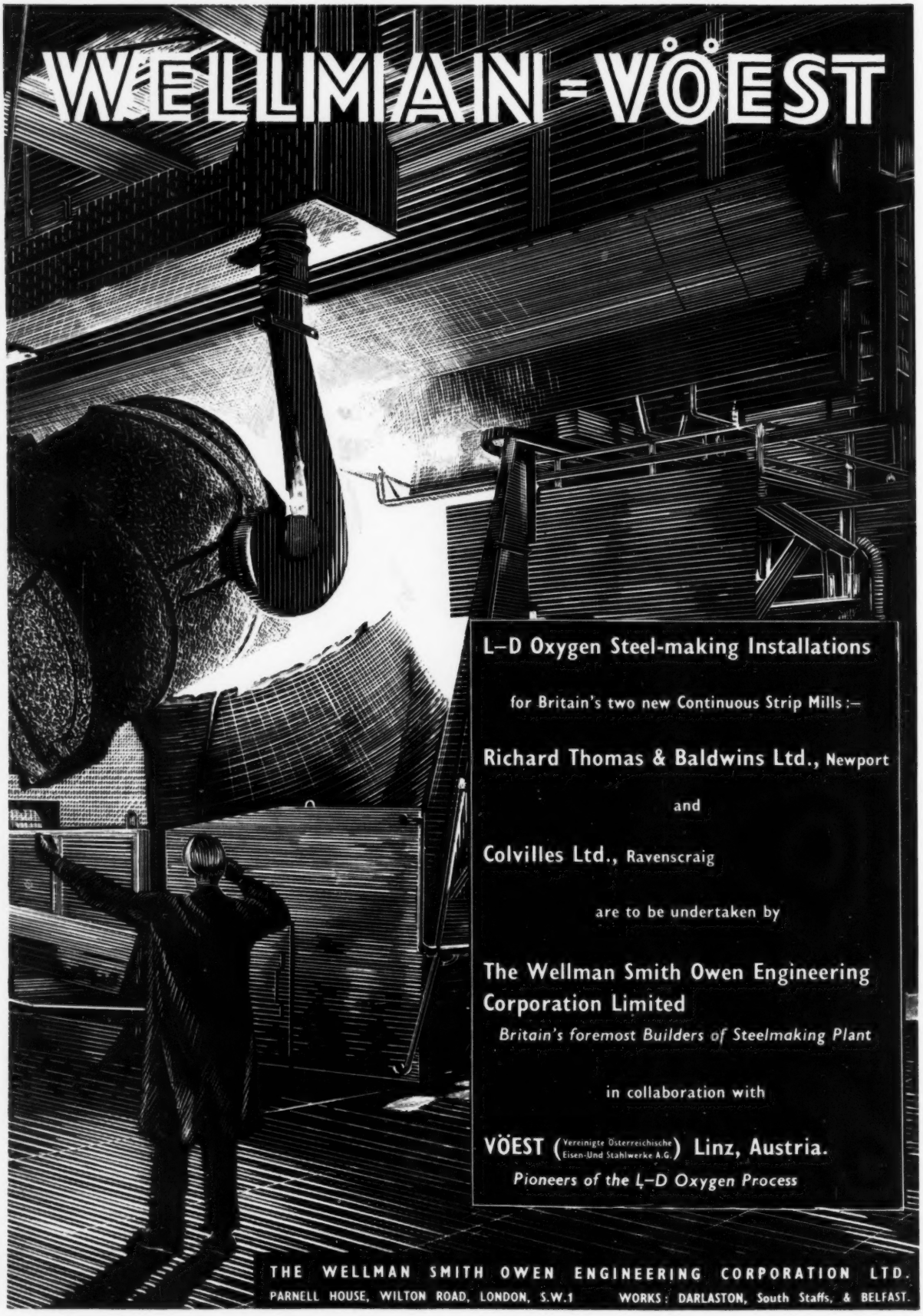
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T. R. CRAIG, O.B.E., T.D.

THOMAS RAE CRAIG was educated at Glasgow Academy and the Lycée Malherbe at Caen. After working for a year at the Normandy works of the Société Métallurgique de Normandie, he returned to the UK and entered the service of Colvilles Ltd to gain wide experience in the company's technical and commercial departments. He was appointed sales director to the company in 1936.

Mr Craig's war service was with the Cameronians and the 52nd Lowland Division, for which he was awarded the O.B.E. in 1945.

In the same year he rejoined Colvilles Ltd, and continued his duties which are mainly on the commercial side. He is also a member of the Executive Committee of the British Iron and Steel Federation, Chairman of No.2 Standing Conference and the Rail Makers' Association, and a Director of B.I.S.C. (Ore) Ltd and Salvage.

Mr Craig joined The Iron and Steel Institute in 1934 and was elected to the Council in 1959.

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Continuous casting at Terni

M. Signora and R. Cardano, A.I.M.

SYNOPSIS

The continuous-casting plant of Societa Terni which came into operation in September 1958 is at present producing 140 mm × 140 mm billets at the rate of 5000 tons per month. In this paper the authors attempt to relate to interested iron and steel technologists the sum of experience acquired during a rather long starting-up period and during operations subject to many vicissitudes during this initial period. 1855

INTRODUCTION

ONCE IT HAD BEEN DECIDED to produce small sections on a modern semi-continuous mill, the management at Terni steelworks was faced with a Hamlet-like dilemma in deciding on the type of roughing mill: were there to be small ingots, conventionally cast, or was there a more up-to-date alternative. Courageously, a modern solution was chosen, and installation of the continuous-casting plant was begun at the Terni steelworks in 1957 while the small section mill was also taking shape. A series of factors both economic and qualitative concerning efficiency, time of installation, and, as already stated, a good measure of courage formed the basis for Terni's decision. It was planned to install a plant with a capacity of 150000 tons of billets per year. The plant would be the first of its kind in the world. With the installation of the Demag semi-continuous mill for small sections it was found necessary to study the most rational solution to the problem of feeding the mill.

The Terni rolling mills do not include a blooming mill capable of rolling large ingots and such a plant would not have been justified by the limited capacity of the melting shop (350000 tons per year of which only 180000 tons would have gone to feed the blooming mill). Alternative solutions to the problem of feeding the new small section mill were to use:

(i) small ingots weighing about 230 kg

(ii) billets rolled on the existing blooming 3-high mill

(iii) continuously cast billets.

The first solution would only have been possible for the rolling of rounds and was considered unsatisfactory for rolling small sections, a decision made easier because of the more exacting quality requirements of the latter products. The second solution was not practicable because of the limited capacity of the mill which was also used for other products. In view of this the continuous-casting solution seemed to be best adapted to Terni's requirements.

Manuscript received 5 May 1960.
Professor Signora is works general manager and Dr Cardano is melting-shop manager at Terni S.p.A., Terni, Italy.

CHARACTERISTICS OF THE PLANT

The plant of the Junghans–Mannesmann Böhler type was constructed by Demag using the experience acquired at Kapfemberg and Hückingen. It casts 60 tons on eight independent casting stands. Table I gives the main operational data, and Figs.1–4 summarize the principles on which this paper is based. Figure 5 shows the layout of the electric furnaces of the Terni steelworks, their capacity, and the flow of liquid steel to the continuous-casting plant.

In a normal cast, details of which will be given later, the ladle placed on the transfer car is transported by locomotive to the casting bay. An 80-ton overhead crane transports the ladle to the casting platform 13 m above ground level. Here the new process, which does not take long to complete, begins. The casting operator directs a common tundish preheated to a temperature of 1000°C, regulates the flow, and observes the behaviour of the liquid metal which enters eight copper ingot moulds through a system of stoppers and nozzles, and is cooled with water sprays.

The operating conditions for each group of four ingot moulds are regulated on the instructions of the mould operator, and the personnel in charge of the cutting device, by an operative in the control cabin. There is independent control of each casting strand. A slow automatic mineral-oil dripfeed into the upper part of the ingot moulds ensures a reducing

TABLE I Operational data

Description	min.	max.	Notes
Hourly production on eight-strand operation, tons/h		60	
Furnace tapping temperature, °C	1650	1700	
Transport of ladle		10 min	
Maximum feed per cast, tons		60	
No. of casting strands		8	
Sizes produced, mm	110 × 110	140 × 140	
Possible sizes, mm	50 × 50	160 × 160	
Height of billets, mm	2800	3000	
Tundishes			Interchangeable, tilting, able to move vertically or horizontally
Tundish refractory			Silica–alumina
Stopper rod refractory			Silica–alumina
Tundish nozzles refractory			Silica–alumina and graphite
Preheating temperature of tundishes, °C		1000	
Preheating of tundishes (oil burners)			Carried out on site and off site in two bays appropriately equipped for preheating
Speed of descent of billets, mm/min	500	1200	
Height of ingot mould oscillation, mm	15	20	
Frequency of ingot mould oscillation, c/min	70	80	
Lubrication of ingot mould			Mineral oil
Cooling ingot mould (water), l./min		1000	
Water temperature entering ingot mould, °C		15	
Water temperature leaving ingot mould, °C		20–22	
Amount of water used in spray cooling, l./min	50	100	
Pressure on withdrawal rolls, kg/cm²		20–40	
Cutting rate of oxyacetylene burners, m/min	0·22	0·52	
		2560	
Speed of burner movement (cutting phase)			Synchronized to speed of descent of billets
Speed of burner movement (return phase), m/min		19	
Discharge system			By bending and conveyor rolls to the hot bank

atmosphere on the surface of the liquid steel and lubricates the walls of the ingot mould.

The billets carried away by the withdrawal rolls on leaving the ingot moulds are spray-cooled to accelerate internal solidification of the billet. The thickness of the solid skin containing the metal which has not yet solidified is about 40 mm for billets of 140 mm × 140 mm on leaving the ingot mould, which is sufficient under normal conditions to resist the ferrostatic pressure of the liquid inside.

In the final section of their descent the billets are cut into 3-m lengths by oxy-acetylene burners whose action is synchronized with the withdrawal rolls. Once the billets are cut they are transferred from the casting machine to boxes which are then placed on a discharge conveyor system and passed to the hot bank. Owing to the independent operation of the individual casting strands it is possible to operate on 8, 6, or 4 strands.

The above is a brief outline of the continuous-casting plant at Terni. However, we consider it necessary to avoid misinterpretation of some of the statements made, two aspects should be emphasized and carefully considered in relation to any continuous-casting project:

(i) the distinctive characteristic of the functioning of the continuous casting process
(ii) the economic background of the new process.

The authors believe that as far as the technological aspects are concerned the continuous-casting process is a success and promises to achieve better results in the near future.

OPERATION OF THE PROCESS

Type of steel

Considerable investigation has been carried out regarding the quality of steel used in continuous casting. Experiments on various qualities, from steel killed with silicon to steel killed with aluminium, and from rimming steel to semi-killed steel have yielded extremely valuable information.

Of the steel at present cast by the plant, 90% has the following analysis, %:

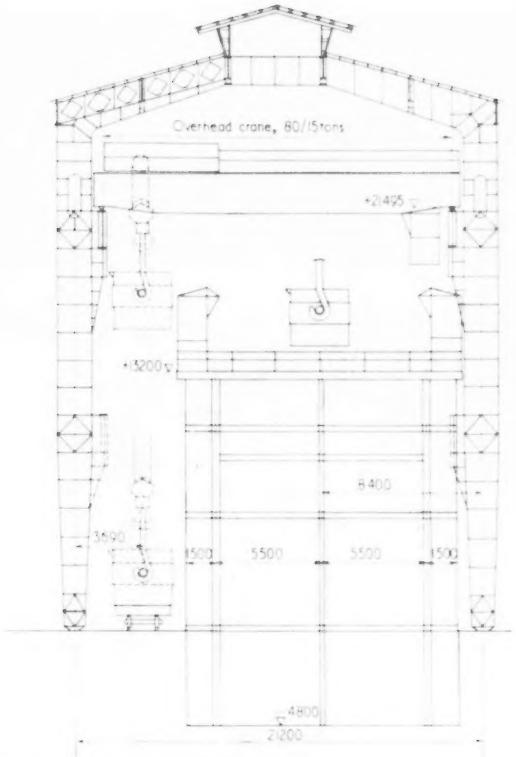
C	S
0·10–0·15	0·05 max.
Si	P
0·10 max.	0·05 max.
Mn	
0·50–0·60	

The steel is produced to black slag and is tapped at temperatures up to 1690°C. Care must be taken that the slag is in the right condition, and it must be ensured that as little slag as possible enters the ladle. No particular care is needed in choosing materials for the burden. Because of the nature of the final product these are of the cheapest type and the steel to be used needs only a short period of refining.

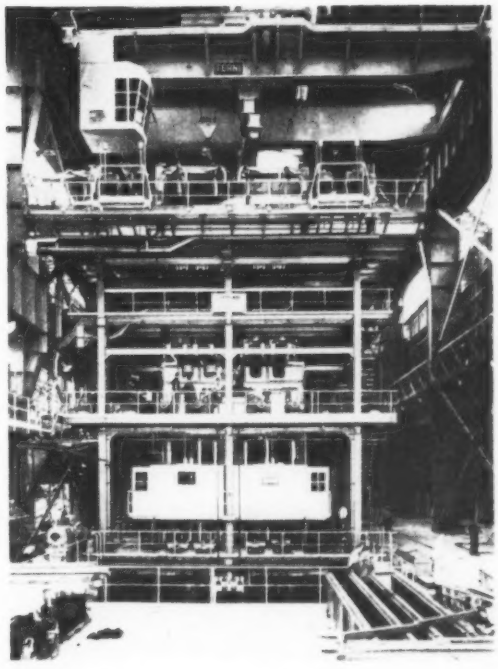
Quality of billets

The billets cast at Terni have very satisfactory surfaces. Their compactness can be influenced by many factors, the most important of which are the speed of casting, and the degree of cooling of the billets themselves during transition from the base of the upper ingot moulds and the axes of the withdrawal rolls. The billets which sometimes appear to have rough surfaces are despatched to the rolling mill without any surface preparation. The surface characteristics of the billets are due to a series of adverse factors aggravated by the large quantity of steel which passes through the plant during a single cast. In fact whereas on the one hand the steel must be particularly hot to overcome the difficulties which occur at the start of casting through the tundish of the eight casting strands, on the other hand the steel is not particularly well deoxidized, which therefore often causes very marked wear on the refractories. This problem will be considered later. Data concerning the consumption of liquid steel on the billet rolling yield and behaviour during rolling is given in Table II.

Certain tests carried out to try to find a more



1 *Section of continuous-casting plant*



2 *Overall view of continuous-casting plant*

specialized use for continuously cast billets have produced sufficiently encouraging results to justify recommending them for use as forging material. All these steels have been produced in an electric furnace using a reducing slag.

Over a wide range of constructional steels Terni's experience has shown that it is possible to obtain very high characteristics of homogeneity. Forgings from continuously cast billets have given very satisfactory results with reduction ratios of about 1:3. It can be confidently stated that these products are equal if not superior in quality to similar products obtained from billets produced in the traditional way. The bright surface and absence of surface defects deserve special mention.

TABLE II Comparison of the consumption of liquid steel and proportion of rejects between continuously cast billets and 150-kg ingots

(*a*) Consumption

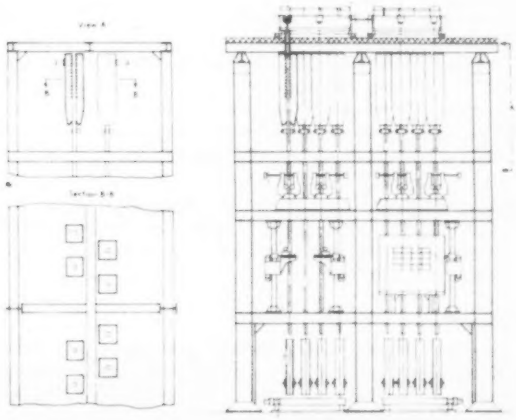
Description	Starting-up period	Jan. 1960
Steel produced in furnaces per 1000 kg of billets obtained, kg	1047	1044
Scrap in ladle, kg	5	5
Steel cast as ingots, kg	9	5
Scrap in tundish, kg	6	8
Billet crop ends, kg	17	16
Discards, kg	—	—
Melting loss, kg	10	10
Billets obtained, kg	1000	1000

(*b*) Proportion of rejects

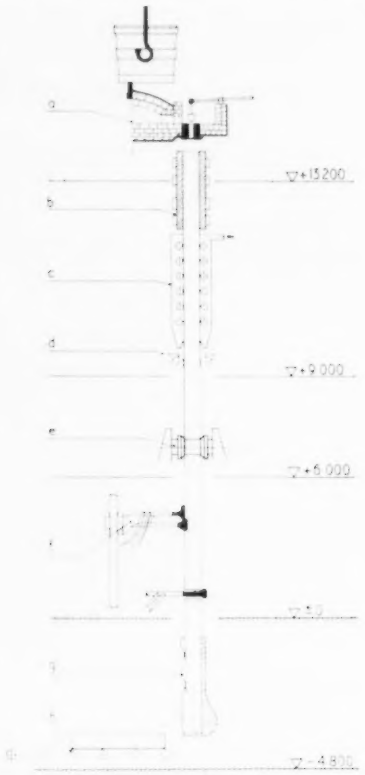
Description	150-kg ingots, %	Continuously cast billets, 140 × 140, %
Crop ends	3·5	3
Steel discards	0·9	0·05
Rolling yield	88·0	91·0

Refractories

The average speed of casting of the plant for billets 140 mm × 140 mm using eight strands is 1 ton/min and a 30-ton ladle must be emptied in 1 h working on four strands. Difficulties which may prevent casting from being carried out at this rate derive from the refractory lining of the tundish, or more precisely the stoppers and nozzles. These parts must obviously be highly resistant to increases in temperature and attack by very hot and incompletely deoxidized metal. In the case of the stoppers, trials of various types of material were laborious and difficult. The results were more



3 *Diagrammatic section of casting platform*



a tundish *b* copper ingot mould *c* spray cooling system *d* guide rolls *e* withdrawal rolls *f* oxy-acetylene cutting equipment *g* binding rolls *h* discharge conveyor system

4 *Diagram of vertical layout of a casting strand*

often than not unsatisfactory. At present ceramic stoppers of 45% Al_2O_3 are being used.

Although it appears that a solution will soon be reached to the problem of refractory resistance, workers at Terni have developed so much skill and expertise in operating the plant that under favourable conditions they are able to change the faulty stopper with only a short interruption of casting. In general, wear of the stoppers is due to flaking or softening which prevents them from functioning properly, especially towards the end of the cast after 40–45 min operation.

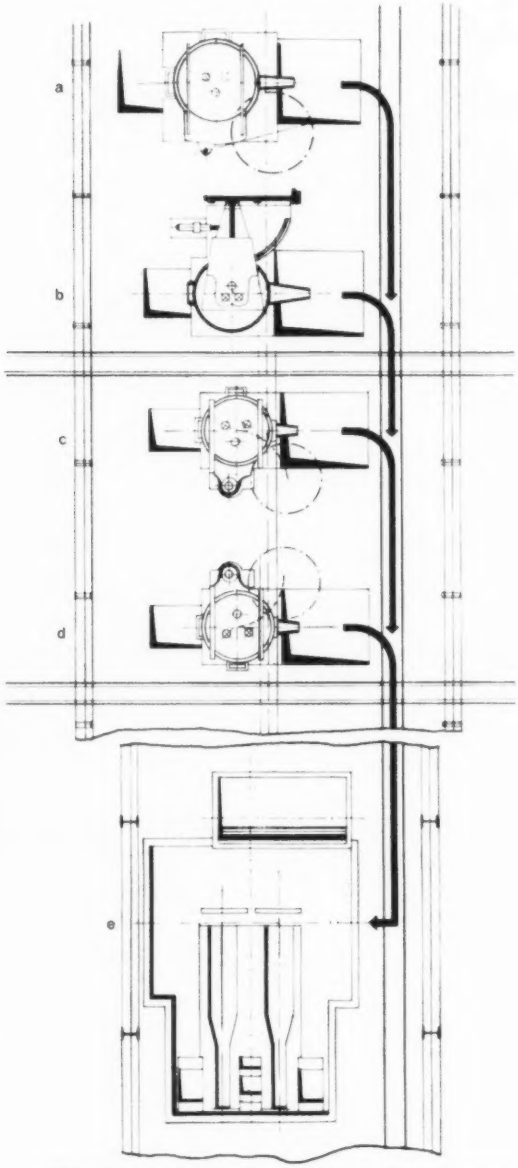
Naturally the difficulties described apply to the continuous casting of mild-carbon commercial steels which, as stated earlier, represent almost all the present production at Terni. These problems are much less in the case of constructional steels produced by reducing slag. Refractory difficulties can be reduced if the casting time is speeded up. On the other hand, the casting time is very closely tied to the efficient operation of the ingot moulds and their intrinsic ability to cool the material cast.

Ingot moulds

From the time the plant started up at the end of 1958, to the present, various types of ingot mould of varying thicknesses and shapes have been tried out at Terni; Fig.7 shows one of them.

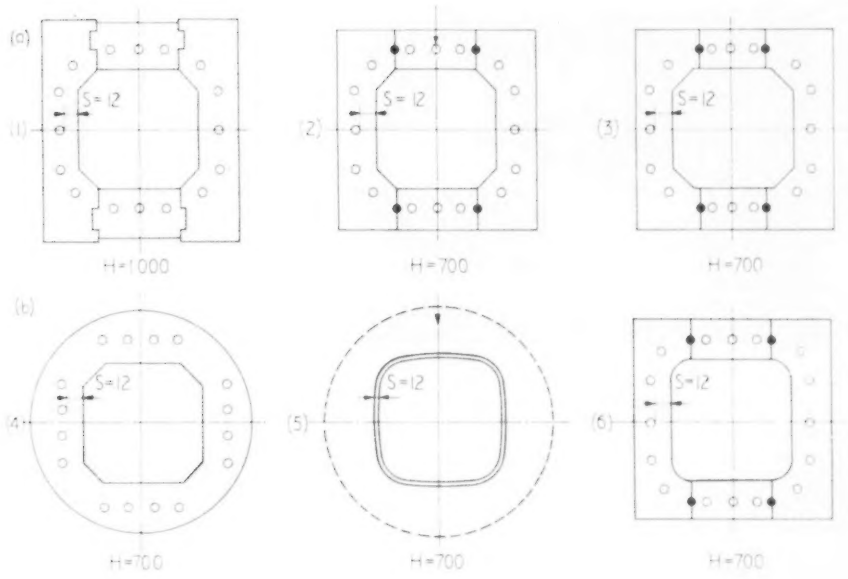
The ingot moulds best adapted to operating conditions at Terni are nos.5 and 6 (*see* Fig.6). Mould no.5 is considered very satisfactory once some adaptations have been made. Mould no.6 consists of four copper elements with an independent cooling system, and a special feature is that the junction between the elements themselves is not effected at the corners.

In addition to ensuring easy repairs which are needed after about 100 consecutive casts, this type of ingot mould permits a rate of casting of about 1 m/min, provided that the rest of the plant is functioning correctly, particularly the cooling system



a 70-ton Lectromelt furnace *b* 40-ton Tagliaferri furnace *c* 35-ton Lectromelt furnace *d* 35-ton Lectromelt furnace *e* Continuous-casting plant

5 *Layout of furnaces and chart showing flow of steel to the continuous-casting plant*



a holes for circulation of H_2O for cooling
b jacket for circulation of H_2O for cooling

6 *Diagrammatic representation of various types of ingot moulds tried out at Terni*

which must function with perfect regularity. This is the critical casting rate (1 m/min) at Terni.

Various problems

In addition to the problems already indicated, there are a number of other factors which contribute to irregular operation of the plant. Table III analyses in detail a complete series of incidents which were revealed by an examination of the operational statistics. This table shows why refractory materials and ingot moulds have been cited as the main causes of incidents. The occurrence of incidents is greatly influenced by the standard of personnel training.

One particular aspect of the problem of increasing the critical casting rate which did not appear to be difficult to solve, was the water-spray cooling of the billet leaving the copper ingot mould. Experience acquired from the first months of operation regarding the life of the copper ingot moulds recommends the use of a 700-mm long ingot mould instead of the 1-m long mould originally used. This substantial shortening was used to reduce to a minimum the factors which might cause injurious permanent deformation of the ingot mould itself. Shortening the ingot mould then meant changing the number and disposition of the water sprays. The additional cooling spray, in the authors' opinion, while not having a decisive influence on the formation of the solid external skin which prevents the liquid metal escaping, has appreciable influence on the total rate of solidification of the billet at the moment it is subjected to the pressure of the withdrawal rolls.

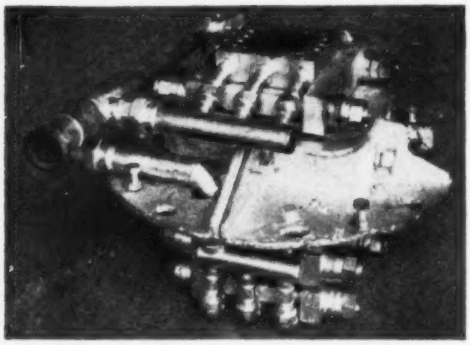
This increased cooling capacity has a considerable influence on the tendency to formation of internal defects, an example of which is shown in Fig.8*a*. This defect then causes defects at the points shown in Fig.8*b*, with a consequent effect on rolling yields. A series of investigations have been carried out to isolate the causes of this type of defect. These took the form of

TABLE III Analysis of delays during continuous casting

Description	Starting-up period, %	Jan. 1960, %	Notes
Disengagement of dummy bar coupling	6·35	7·83	
Breakdowns and interruptions on the cutting platform	11·09	13·04	
Deterioration of tundish stoppers	33·20	17·39	Reduction since December
Deterioration of casting nozzles	4·54	17·39*	Exceptionally high figure only in January
Ingot moulds ('jacket' emptying and slipping oscillation)	23·78	24·35	Accidents which generally cause billets to break on leaving ingot mould
Casting (errors on part of operator)	9·08	6·96	
Withdrawal and guide rolls	2·00	1·74	
Power failure	0·93	1·74	
Failure of O_2, H_2O, C_2H_2 supply	0·61		
Excessive deformation of billets	4·14	5·22	
Others (H_2O boxes, ladle, deformed billets)	2·54	0·86	Gradually diminishing
Insufficiently hot steel (furnace)	1·14	0·86	
Stoppages (ladle nozzle, ladle)	0·60	2·62	Not a representative figure
	100·00	100·00	

	No.	%	No.	%
Casts made	815	100	188	100
Casts made without incidents	264	32·3	103	54·7

* In the starting-up period stoppers were thought to be the cause of delays which later proved to be partly due to deformation of the nozzles.



7 *Overall picture of ingot mould (no.6 in Fig.6)*

measurement of the height of the steel remaining liquid in the inside of the billet, noting the temperature of the tundish, varying the speed of descent and the secondary cooling conditions, and keeping the pressure of the withdrawal rolls constant (30 atm) and also the cooling of the ingot moulds (1000 l./min of water). Tests were then carried out which consisted of reducing the pressure of the withdrawal rolls (from 30 to 20 atm) but leaving the other casting conditions, i.e. speed and secondary cooling, unchanged.

These tests, which would take too long to describe in detail, have shown that in the 140 mm × 140 mm billet, solidification is complete at a distance of 2400 mm beyond the axes of the withdrawal rolls. Working with a pressure on the rolls of 30 instead of 20 atm can very often cause internal cracking located on the billet at right-angles to the axes of the transporter rolls.

There are no doubt many other factors influencing the quality of the billets, and these are an obstacle to systematic experiment. In fact whereas in ingots cast by the traditional method the rate and temperature of casting are the main factors affecting the quality of the ingot, in the case of continuous casting, as many other research workers have already pointed out, the ingot-mould cooling system and its efficiency, the secondary cooling of the billet, the rate of descent, the reducing atmosphere system, the pressure of the withdrawal rolls, and the type of cooling after oxy-acetylene burning, etc. must be taken into account.

All these considerations vary in importance according to the quality and type of steel passing through the continuous-casting plant. At Terni under the present system the main problems are connected with the need to cast large quantities of commercial steel while at the same time trying to reduce stoppages and plant-wear to a minimum. The qualitative requirements for this category of products are only a good surface and sufficient internal compactness of the billets.

Consumption and costs

Table IV shows the main items which go to make up the cost of producing continuously cast billets together with the authors' comments on certain items. The first relates to labour employed, and is obviously closely linked with the capacity at which the plant works. This, as we have seen, is at present low.

The incidence of refractory consumption varies according to the size of the cast, i.e. from 30 to 70 tons.

TABLE IV Main production costs

Description	Unit of measure	Starting-up period	Jan. 1960
Labour	h/ton	3·03	2·51
Calcium carbide	kg/ton	6·6	6
Refractories (excl. ladle)	kg/ton	12	12
Electric power*	kWh/ton	29·6	24·8
Maintenance	lire/kg	0·71	0·63
Lubricating oil	kg/ton	0·30	0·30
Cost of ingot mould†	lire/kg	0·50	0·50
Oxygen	Nm^3/ton	8	8·5

* Excluding overhead crane, lighting, and locomotive service
† Approximate figure due to lack of adequate operating data

The figures given in the table relating to the month of January represent the higher limit of consumption, as in this month the plant worked on 30-ton casts. As to the cost of the copper ingot mould, this figure can certainly be reduced.

While the authors are aware that in discussions for and against continuous casting it is usual to say that continuous casting saves the cost of the ingot moulds, their high price (compared with the 'nothing' often quoted) is far less than that of the iron ingot moulds used in the traditional casting pit.

In fact in the case of small ingots of 150 kg, cast in the normal way, the pig iron cost per kg of steel is 0·98 lire compared with 0·40–0·50 lire*of the copper ingot mould.

Personnel

The importance of the human factor at Terni, especially of training personnel, must be emphasized.

Work began with 30-ton casts using four casting strands, i.e. half of the plant. The personnel needed in operating at this rate are as follows:

1 charge hand (shift manager)
1 first mould operator
4 mould operators
1 platform operator
1 first cut-off man
2 cut-off men
3 bricklayers
1 crane-operator

This does not include personnel needed to discharge and cut the billets produced.

Arrangements were made to train personnel at continuous-casting plants abroad and to make careful selection during operations. In fact no special demands are made on personnel when the plant is operating normally, but to deal with the inevitable difficulties which so often occur during casting, it is essential to have well trained quick-thinking men. Complete emptying of the ladle is one of the more important cost elements and very dependent on the continuity of operation of the casting strands with which casting began.

This brief description of the results obtained on the Terni plant concludes the technical aspect which, after taking into account the effects of mechanical improvements, simpler instrumentation, and improvements in the quality of certain materials, can only be described as satisfactory.

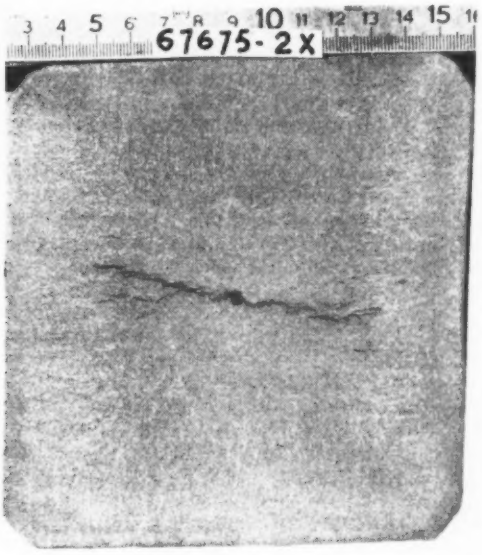
* £1 sterling = about 1730 lire (June 1960).

Speeding up production rate

Maximum utilization is a fundamental condition for economic working when producing, as at present, commercial quality steels. A continuous-casting plant will give satisfactory results provided that the number, disposition, and capacity of the furnaces have been carefully worked out. The authors believe that this is the most difficult problem to solve inasmuch as the continuous-casting plant has to be integrated with a production cycle already existing. To produce 12000 tons of billets per month, which is the annual amount estimated, the Terni plant has to be fed with the entire production of one 70-ton and one 30-ton electric furnace in 24 h. To attain this rate of operation even when the plant is operating perfectly is difficult in view of all the unforeseen factors which may hinder the planned production programme of the furnaces.

At first the personnel worked two complete shifts on eight casting strands. Then experience showed it was desirable, so as to adapt the needs of the melting shop to those of the continuous-casting plant, to work three shifts so as to absorb the entire production of one 30-ton electric furnace in 24 h. By the latter method four casting strands were always in operation. In the event therefore of these four strands breaking down during casting they could always be repaired without casting being interrupted.

This scheme of operation was suggested by various associated factors. It did not bring about any appreciable speeding up in the present rate of operation of



a

b

8 (a) *Typical internal defect due to increased cooling capacity, and* (b) *consequent further defects*

about 5000 tons/month. To do this it would be necessary to use the 70-ton electric furnace sending two to three heats for casting in 24 h. This is only practicable if personnel are transferred from the normal casting pit to the continuous-casting plant. In addition, this is dependent on emptying the ladles in as short a time as possible. Whereas to empty a heat of 30-tons operating on four strands normally takes 1 h, it can take up to 70–75 min if one or two casting strands have to be stopped during operations. In other words the total operating time for casting the production of one single 30-ton electric furnace is about 12 h compared with the plant's theoretical time of 9 h.

This particular aspect depends on a large number of factors and appreciably lessens the possibility of achieving a big increase in the quality cast. It must also be borne in mind that with eight-strand casting at least 24 ingot moulds are required, taking into account normal repair of the ingot moulds after a cycle of about 100 casts. The total life of the ingot moulds should be about 500 casts but the authors feel they cannot yet comment on this owing to lack of sufficient information from direct experience.

The problem of eight-strand operation at high rate of production has not been underestimated and experience has shown the necessity of a well adapted plant, and planning and co-ordination of operations so as to ensure a rapid return to the production line of the ingot moulds to be repaired. In fact this aspect of operations has had, and continues to have, a negative effect on attempts to speed up production as has been proved in practice.

CONCLUSION

The authors have attempted to show as concisely as possible how, in two years of operation, experience and practical knowledge of the functioning of continuous casting has been accumulated.

The main characteristics of a plant which is better defined as a 'delicate and complex production unit' rather than a 'massive steelmaking plant' are as follows:

1. Continuous casting, if it is to be an economic mass-production process, must work at higher capacity than normal (60–70% rather than 25–30% which is the present rate at Terni). The authors consider that it is technically possible to operate the Terni plant at about 60% of capacity. However, this figure is subject to the solution of planning problems which may vary from time to time.
2. Continuous casting is a process which transforms steel from the liquid to the semi-finished state and therefore requires rapid steel production.
3. Continuous casting seems to fit in perfectly well with the so-called 'pneumatic processes' (traditional converter, L–D, Kaldo, etc.) which can produce rapidly the mass quantities needed by the adjacent plant.
4. If the steels cast are special or of very high quality, then conclusions 1–3 must be reviewed.
5. The quantity of steel sent to continuous casting is rather less than the maximum quantity which could be continuously cast because of the need to take into account the effect of stoppages or incidents on one or more of the casting strands; the casting time must not approach the time limit of refractory resistance. At Terni, with refractories at present used, the best operating rate is 40 tons when casting on eight strands (40 min). In the case of breakdowns on two strands (60% probability) casting would take a maximum of 60 min.
6. It is best to keep a certain number of operational strands in reserve which will depend on the number of strands normally used so as to ensure the disposal of the steel in the ladle or that a subsequent cast can be poured even if breakdowns have suspended operation of part of the plant.

Degassing of steel by vacuum casting for the production of castings and forgings

V. Scalise, A. De Negri, and V. Piccardi

INTRODUCTION

THE PROBLEM of supplying high-quality steels for forging ingots, always a very serious one, is becoming increasingly acute although some excellent results are being obtained. The development of new techniques, the need for increasingly high-quality materials for particularly complex and stringent requirements, and modern methods of testing have given an impulse to study and research aimed at obtaining metal of ever increasing purity free from any hidden defect.

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SYNOPSIS

Vacuum degassing provides one of the most efficient means of reducing the H_2 content of steel to a level at which it does not give rise to flaking. Vacuum degassing has been practised at the Società Italiana Acciaierie Cornigliano (SIAC) since the end of 1958; this paper describes the plant and gives a detailed account of vacuum ingot-mould degassing and ladle-to-ladle degassing, together with the results achieved and conclusions reached after the first year of operation. 1856

Iron- and steelmaking techniques based hitherto on purely empirical methods have become more and more elaborate owing to the application of fundamental laws of chemico-physics. It will suffice to recall in this connexion the law of mass-action, and the principle of the distribution of the phases which, defining the quantitative reactions by means of the relative equilibria which occur during metallurgical processes, have established the relations governing the reaction between the metal and the slag.

The application of these principles has served as a guide and means of control for producing steel more scientifically to meet more and more exacting specifications. Despite this it has not been possible to eliminate or even reduce below given limits certain harmful elements which cause concern because of the defects which they produce in the metal. The most important of these defects originate from inclusions of gases. Of these, H_2 shares the responsibility for certain defects and is considered to be the principal or, possibly, the sole cause of the defect known as 'flaking'.

The presence of H_2 in the steel therefore poses for steelworks serious problems which today, for the most part, have been solved by the introduction of vacuum casting. This process is the practical application of an already well known and clearly defined law of chemico-physics which has as its fundamental aim the reduction of the H_2 content in steel to values which practically rule out the possibility of any resulting defect.

The steel still contains some H_2 which is very difficult to remove. The maximum reduction of H_2, which can amount to a quite high percentage of the total H_2 reduction, happens at the moment of solidification in the 'liquidus/solidus' interval. Despite this reduction, however, the quantity remaining is still appreciable, varying from a maximum of 10–14 $cm^3/100$ g to a minimum rarely below 4–5 $cm^3/100$ g.

With this amount of H_2 the danger of flaking is still present. It is true that it is possible to minimize or completely eliminate the harmful consequences of these defects by taking certain measures (e.g. anti-flaking annealing) but it is quite impossible to ignore the importance of being able to operate with the certain knowledge that the steel used is incapable of flake formation. Experience has shown that to obtain such steel the amount of H_2 must not reach 2·5 $cm^3/100$ g.

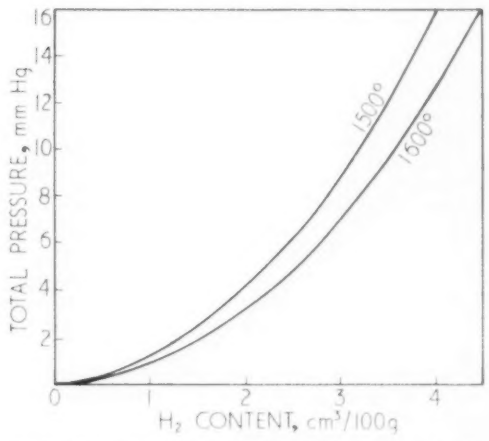
All the known methods of reducing the intake of H_2 into the steel, such as the drying of ferro-alloys, ore, and additions, are very effective and essential but they cannot by themselves resolve the difficulty. Vigorous reaction in the bath, a violent boil to enable the H_2 to leave the steel and enter the gaseous bubbles arising from the hot metal, is also an effective method of reducing H_2, but as shown in the example already described, it cannot completely solve the problem. The H_2 comes from the atmosphere itself in which the reactions take place.

The vacuum-stream degassing process is based on Sievert's law of the square root, according to which

$$[H]=K\sqrt{PH_2} \quad \ldots\ldots(1)$$

where [H] is the percentage in weight of the H_2 in the iron, K is the coefficient of dissolution, and PH_2 is the partial pressure of H_2 in the atmosphere. The H_2 content in the steel increases with the square root of the partial pressure of H_2 in the atmosphere. The coefficient K, called the coefficient of dissolution is, in its turn, a function of the temperature of the steel. This has been calculated by various workers, e.g. Morozov and Kamanchov, and also Martin, Schenk, Luckmejer, and Hesse. According to Schenk's formula the coefficient K has a value of

$$K=275\times10^{-5}.\ t°C-175{\cdot}5\times10^{-5} \quad \ldots\ldots(2)$$

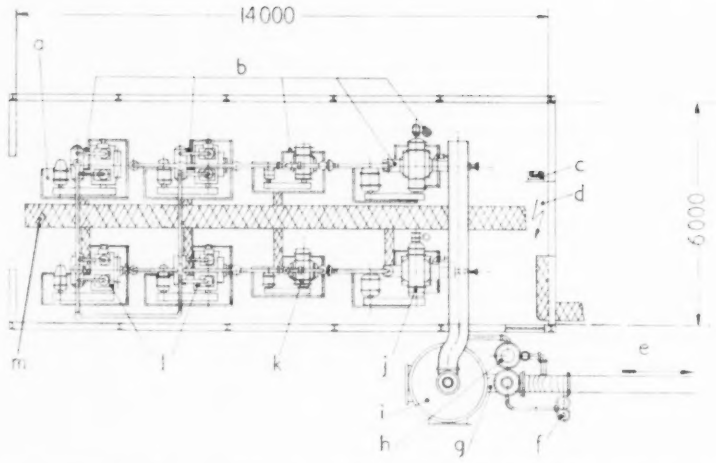


1 *Ratio of* H_2 *content to total pressure in the vacuum chamber*

The importance of reducing the atmospheric pressure to very low values results clearly from equation (1). If, using equation (2) for K, the curve relating to Sievert's law is drawn in the temperature band required by the steelworks, i.e. to 1500° and 1600°C, and related to the total pressure values in the vacuum chamber, it is obvious that to be certain of obtaining flake-free steel (which requires an H_2 value not exceeding 2·5 $cm^3/100$ g) there must be an operating pressure of less than 5 mm (*see* Fig.1).

It must be mentioned here that Sievert's law assumes almost perfect homogeneousness of the liquid metal and constant pressure; and, so that the law of equilibrium may be verified, other factors must be allowed for, particularly the time of vacuum treatment.

The vacuum-casting process has other advantages, such as the reduction of oxygen in the steel. In this connexion interesting experiments have recently been carried out by Tix, Bandel, Conpette, and Sickbert on steels for inductor shafts of analysis 0·28%C, 1·25%Cr, to 0·35%Mo and 1·95%Ni. It was found that the O_2 value was substantially reduced (0·002% compared with 0·005–0·007% for similar steels cast in air). This O_2 value was also found to be constant for the whole length of the shaft (10·9 m) and along the sections to the head and the base. Similar experiments carried out by other workers agree in general with these results. Substantial improvements in mechanical characteristics, particularly in ductility, are generally acknowledged by all concerned with the problem but it is unanimously agreed that all other advantages are of secondary importance compared with the decisive function of vacuum casting which is today the only effective way of reducing the H_2 value below 2·5 $cm^3/100$ g.



a base motors *b* pipe for water cooling *c* telephone link with vacuum chamber *d* electrical control panel *e* to vacuum chamber *f* battery of nitrogen cylinders *g* differential mercury gauge *h* small filter *i* large filter *j* Ruvac 57 pump *k* Ruvac 45 pump *l* S720 pump *m* passage

2 *Vacuum pumping system*

The process adopted by SIAC for vacuum casting is based on the degassing of the steel stream in a vacuum. The plant came into operation at SIAC in September 1958 and in little more than a year has enabled 300 steel casts weighing from 7 to 150 tons to be made.

THE VACUUM DEGASSING PROCESS

In the process adopted by SIAC the vacuum is created in the chamber by a mechanical pumping system. In an appropriate cabin, 118 m from the vacuum chamber, a group of pumps made up of two parallel banks is installed (Fig.2). Each bank has three preliminary pumps (2/S 720+1/Ruvac 45) and one Ruvac 7. The preliminary pumps, so called because they are first to come into operation, are designed to reduce pressure in the vacuum chamber from 763 mm to 30 mm. The last Ruvac pump begins operation automatically as soon as pressure is down to 30 mm and reduces pressure to 0·05 Torr. By this method, when the ingot mould or the ladle is already in position in the chamber the time needed to reduce pressure from 763 mm to 30 mm is about 60–90 min. A further 30 min is necessary before pressure falls below 1 mm.

A main suction manifold of 500-mm dia. links the pumps with the vacuum chamber. At the base of the manifold close to the vacuum chamber two electropneumatic valves are located to pump in the atmospheric air when casting is completed. Another valve with hand control is located near the control panel. Near this control panel there is also a battery of nitrogen cylinders connected with the vacuum chamber by pipes running parallel to the main manifold. Air is pumped through a filtering system close to the pumps. This consists of one sack filter (4 sacks), known as the preliminary filter which operates while the pressure is being pumped from 763 mm to 30 mm, and a second sack filter (37 sacks) which also comes into operation below 30 mm. The air is thus discharged into the atmosphere through the manifold.

In the immediate vicinity of the vacuum chamber are the control panel for the pumps and filters, a mercury gauge for measuring pressure, and the 'alfatron' device for measuring and recording pressure. Television cameras and screens to facilitate casting control are in course of being installed. The total installed capacity of this plant is 165 kW. Requirements of water for cooling are 8 m^3/h, and the total quantity of air pumped is 6000 m^3/h (from 763 mm to 30 mm) and 15000 m^3/h (from 30 mm to 10^{-2} mm). The vacuum chamber of welded steel plate 25–40 mm thick has a diameter of 4230 mm and a height of 7000 mm. With present ingot moulds ingots of a maximum weight of 160 tons can be vacuum cast. It will shortly be possible to cast larger ingots.

The top of the vacuum chamber has round its circumference a groove in which is placed a neoprene ring which ensures that the chamber is hermetically sealed when the cover is placed on. The cover, made of cast steel, is 750 mm in dia. and closed by an aluminium disc 2 mm thick. The aluminium disc ensures hermetic sealing while the pumps are operating before casting begins. It is soon covered and melted by the steel poured from the intermediate ladle at the moment of casting. The circular protuberance *A* (Fig.3) round the aluminium disc also has a groove for a second neoprene ring. In this groove the base of the intermediate ladle is fixed. A valve with pressure gauge connects the small vacuum chamber (created between the bottom of the intermediate ladle and the aluminium disc) to the vacuum chamber.

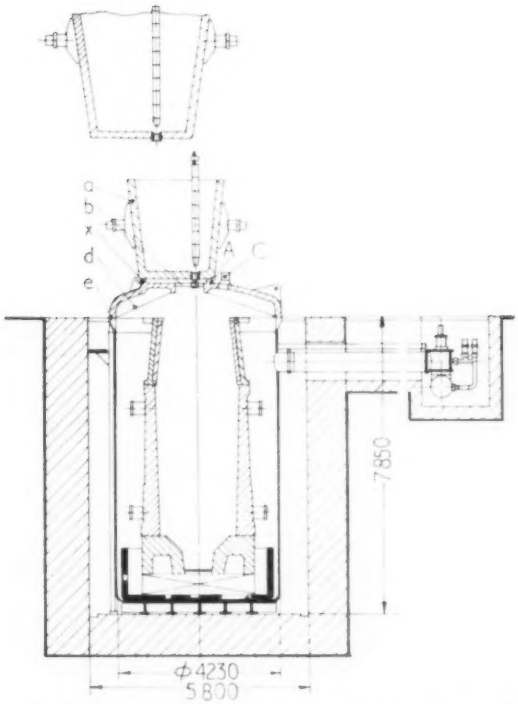
Two windows allow the progress of casting to be observed from above from start to finish; these are positioned so that from one it is possible to obtain a good view of the surface of the steel and from the other the steel casting and the height attained by the steel in the ingot mould can be observed until the feedhead is completed.

VACUUM CASTING

Two different methods of vacuum casting are used at SIAC. The first is for large forging ingots which are cast directly in the vacuum chamber; the second is for ingots or foundry castings, the steel being vacuum treated by transferring it from the intermediate ladle to an ordinary steelworks ladle placed in the vacuum chamber, after which the ingots or castings are then air cast.

Casting of large forging ingots: preparation of base plate, ingot mould, and feederhead

The well heated and cleaned base plate is placed in a central position on a refractory-lined iron plate located



a intermediate ladle *b* aluminium disc *x* neoprene ring *d* protective sheet *e* neoprene ring *A* rim with groove for neoprene ring *C* valve with pressure gauge

3 *Section of vacuum ingot casting installation*

on the floor of the vacuum chamber. The ingot mould is placed on it. The mould is thoroughly cleaned, heated, but not dressed. Particular care must be taken with the feederhead which, being of a conventional type, must be subjected to prolonged heat-treatment to ensure perfect dryness without which it would not be possible to attain the desired vacuum pressure. To avoid particles of crushed refractory falling into the ingot mould during casting, the entire inner surface of the feederhead is lined with steel sheet 0·5 mm thick. Once the ingot mould and the feederhead are in position they are then tightly secured to each other to ensure a perfect seal and avoid even the slightest movement of the feederhead in relation to the ingot mould under the very high ferrostatic pressure.

A leakage of steel in the vacuum chamber is quite different from a leakage during a normal air cast, and would have much more harmful results. It is still necessary to heat the equipment after it has been prepared, then, 3 or 4 h before casting, the vacuum chamber is closed with the appropriate cover. The seal between the chamber and the cover and the cover and the atmosphere is checked, then pumping begins. As already stated, in about 120 min an extreme degree of vacuum usually between 0·05 and 0·1 Torr can be attained before casting.

When the cover of the vacuum chamber is secured the intermediate ladle is placed on it, the join being sealed with a neoprene ring (*see* Fig.3). The intermediate ladle must be preheated to about 500–600°C at the moment it is to receive the cast steel. Under these conditions casting can begin.

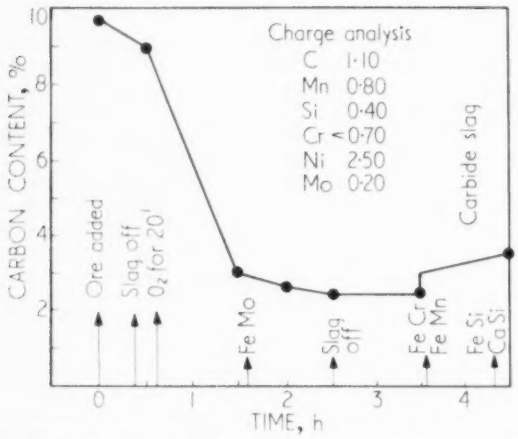
Casting

Furnace treatment of steel for vacuum casting is no different from that of steel to be cast by conventional methods except for one extremely important detail: casting temperature. Figure 4 shows a melting chart for the operation of a 30-ton electric furnace producing Cr–Ni–Mo steel for vacuum-cast rotors.

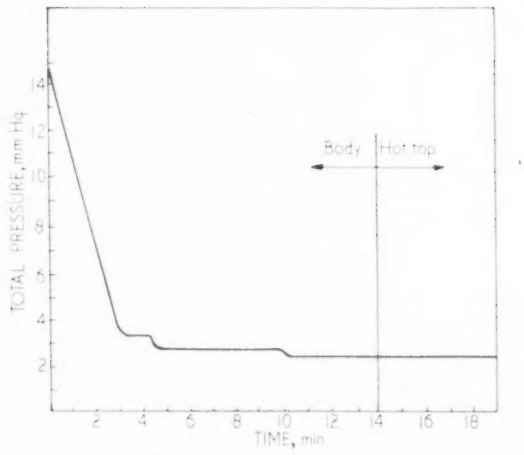
The steel intended for vacuum casting passes from furnace to conventional melting-shop ladle and then is transferred from the melting ladle to the intermediate ladle. From here it is teemed into the ingot mould located in the vacuum chamber (*see* Fig.3). It is evident that these transfers from ladle to ladle may involve quite considerable falls in temperature, which is why the steel furnace is tapped at a higher temperature than would be necessary for a comparable air cast. The temperature for vacuum casting is naturally related to the type of steel, carbon content, alloying elements in the steel, and quantity of steel to be tapped. In general a difference of from 20° to 30°C compared with a comparable air cast will ensure a good cast.

When several furnaces are used (in the case of a very large ingot for example) the temperature of the steel cast first into the intermediate ladle must be about 20°C higher than the steel from the furnaces subsequently tapped. The fall in temperature of steel first tapped into the intermediate ladle will be higher than that of steel from the other furnaces. When all the additions have been made and the desired temperature has been attained the steel is tapped from the furnace into the melting-shop ladle. This ladle is then transferred on to the intermediate ladle, which has previously been fixed on to the cover, and the steel is transferred to the latter. At the same time the vacuum in the vacuum chamber is reduced to 15 mm Hg by the introduction of nitrogen. When the intermediate ladle is about half full a vacuum is created in the small chamber between the base of the intermediate ladle and the aluminium disc. As the steel rises in the intermediate ladle the temperature of the steel is measured using an immersion thermocouple which is applied to the intermediate ladle. Casting can begin as soon as the recorded temperature has fallen to the desired level.

It has been stated that at the moment of transferring the steel from the melting-shop ladle to the intermediate ladle, the pressure will be about 15 Torr, depending on the size of the ingot to be cast. The reason why this pressure value is necessary when casting begins is as follows: a characteristic of vacuum casting is the very fine shower of droplets. The degree of dispersal depends on the surrounding pressure in the sense that the higher the pressure the less dispersed is the stream. However, while it is considered perfectly normal to have a metal cone with a maximum angle to the vertical of about 20°, a cone with a greater angle cannot be considered normal because in this case part of the metal would probably, particularly at the beginning, strike the walls of the ingot mould or even the walls of the feederhead and then fall, seriously harming the ingot. On the other hand it is evident that even a maximum angle of 20°, although quite normal when the surface of the steel has already reached a certain level in the ingot mould, is not normal at the beginning of casting, particularly if these are small-section ingots. It is, however, standard



4 *Typical heat chart of a heat for the production of a* Cr–Ni–Mo *steel*



6 *Vacuum in the degassing chamber in pouring a 100-ton ingot of* Cr–Ni–Mo *steel*

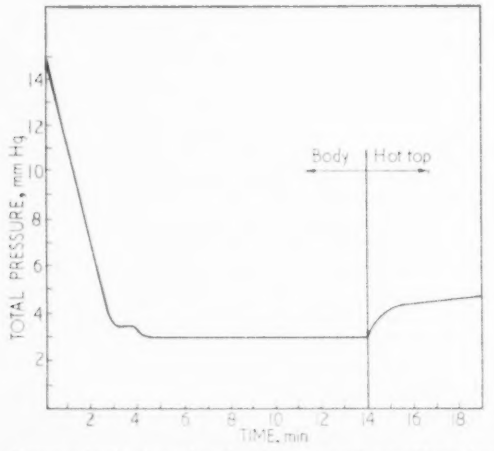
practice at SIAC to begin casting at a pressure of about 15 Torr. Once the central plug is open it is possible, by examining the metal shower, to reduce pressure gradually to the lowest extent possible. Figures 5 and 6 show two examples of vacuum casting of two ingots in Cr–Ni–Mo steels. The vacuum values are shown vertically and the casting times are shown horizontally. If the correct procedure is adopted each time and the temperature is as required for the type of steel, the visibility is always perfect. The stream is well dispersed without harmful defects and does not cling to the walls of the ingot mould. Pressure can then be reduced, as shown in the two diagrams, to 3–4 Torr and even less.

The appearance of the vacuum-treated steel in the ingot mould is similar to a rimming steel. In effect this is another advantage of vacuum casting: the reaction between C and O of a killed steel develops later with consequent reduction of the oxygen dissolved in the metal; the reaction is possible since, corresponding to the pressures normally reached in vacuum casting, the affinity between C and O is greater than the affinity between O and Al. Pressure is, however, regulated as a function of the appearance of the steel which, as stated, is in its turn principally a function of the casting temperature.

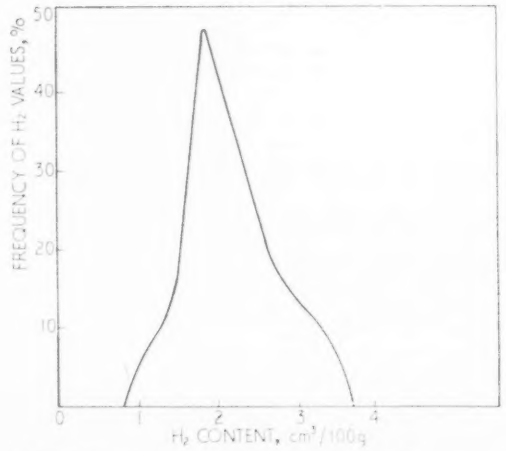
It is important to attain a very high degree of vacuum, below 5 Torr, in order to obtain satisfactory results in eliminating H_2. Only under these conditions will the H_2 value be lower than 2·5 $cm^3/100$ g and will there be a guarantee of freedom from flaking.

When the feederhead is reached, casting is stopped for a moment and then resumed at a very slow rate until completion. Sometimes peripheral bubbles may appear in the feederhead owing to absorption of H_2 from the feederhead refractory or to the melting of the protective sheet; it is necessary in this case to limit bubbles by slowing down the rise in the steel at a late stage or increasing the pressure in the vacuum chamber by letting in nitrogen.

As illustrated, in both cases it can be clearly seen how satisfactory vacuums can be obtained, and although in the cast shown in Fig.5 it has been necessary to take action to limit very small bubbles in the feederhead by raising the pressure slightly (from 3·5 to



5 *Vacuum in the degassing chamber in pouring a 100-ton ingot of* Cr–Ni–Mo *steel*



7 *Frequency curve of* H_2 *content in degassed steel*

TABLE I Examples of casts of various steel

Steel type	Cast no.	H_2 cm³/100 g Furnace	S.V.	%
C–V	06970/71	5	2	60
Cr–Ni–Mo–V	02878–79	5	1·5	70
Cr–Ni–Mo–V	02849–50–51	3·7	1·8	51
C–V	03578–79	4·9	2·3	53
Cr–Ni–Mo–V	01775–77	3·8	1·7	55
Cr–Ni–Mo–V	01998–98	4·4	1·0	77
C	02103	3·9	1·8	54
C–V	06567	3·6	2·0	45
Cr–Ni–Mo	06855	4·4	2·0	50
Cr–Ni–Mo	03970–71	6·8	2·6	62

6 Torr), in the cast shown in Fig.6 pressure has been kept constant and then reduced to 3·5 Torr without the least sign of disturbance.

During casting into the ingot mould it is very important that an observer should be able to follow and continually check the level of steel in the intermediate ladle and supply the necessary information to the man controlling the cast on the lower level. At an appropriate point on the stop-rod a metal seal is applied to avoid air filtering in through the refractory. A fall in the level of the steel below the disc would jeopardize the success of the cast. To avoid difficulties of this kind it is important that this level in the intermediate ladle should be reached when the steel rising in the ingot mould has reached the feederhead. It is for this reason that the metal sealing disc is applied immediately after the first refractory tube of the stop-rod from below (about 50 cm from the bottom of the ladle). It is, however, better to keep it at a higher level, e.g. 80 cm, until the steel reaches the feederhead.

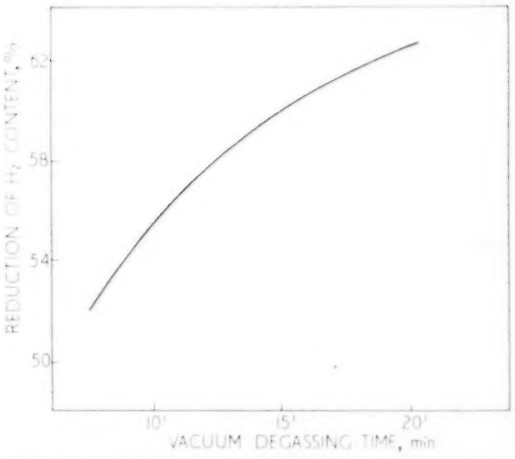
When casting is complete the atmospheric air is let in to the vacuum chamber until normal pressure is reached and then the intermediate ladle is quickly removed and the cover and head of the ingot reheated. At SIAC the head of the ingot is reheated using the Grauger system consisting of two 100-mm dia. electrodes placed 225 mm apart. This provides a maximum capacity of 140 kVA with a maximum amperage of 1000 A. The time of reheating is, of course, related to the dimensions of the ingot.

ELIMINATION OF HYDROGEN

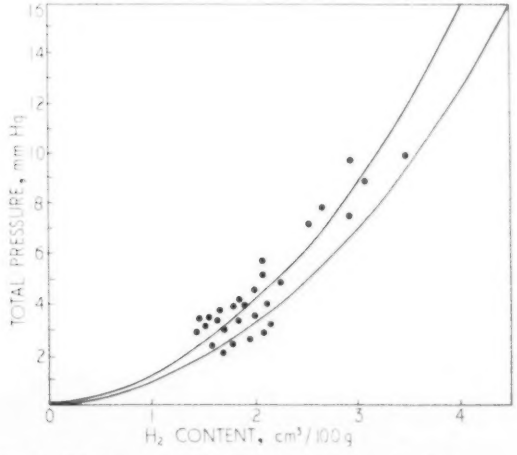
From the results obtained in this first year of vacuum casting at SIAC it can be affirmed that using this process the hydrogen is reduced to very low values. It is sufficient to operate with a pressure of under 10 mm since a reduction of 50% can easily be obtained, and at lower pressures a reduction of over 60% is possible.

Table I shows a few examples of casts for widely varying types of steel giving the H_2 contents of samples taken from the furnace shortly before casting and after vacuum treatment. The H_2 value was determined by the vacuum-extraction method at 700°C. Figure 7 summarizes numerous data and shows the frequency at which the H_2 values shown were obtained.

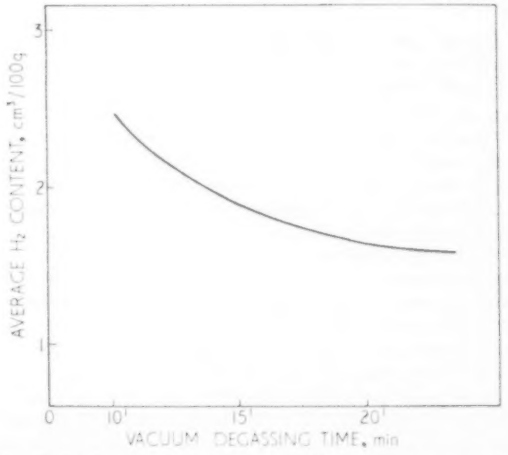
It is now unanimously agreed by all technologists concerned with vacuum casting, and in accordance with Sievert's law of equilibrium, that to obtain appreciable reductions in H_2 values on an industrial scale it is necessary to operate at a pressure below 10 mm. To obtain H_2 values so low as to provide a guarantee against flaking, operating pressure must be below 5 mm. In Fig.8 the results of certain casts made at SIAC are given. The H_2 contents after vacuum treatment as a function of the pressure reached in the



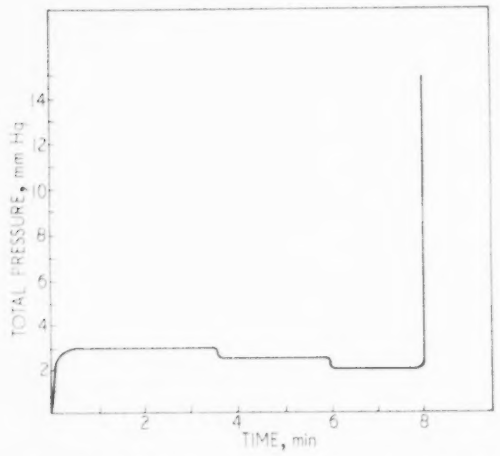
9 *Ratio of reduction percentage of* H_2 *in steel to vacuum treatment time*



8 *Equilibrium curves of* H_2 *in the degassing chamber*



10 *Ratio of average* H_2 *content in steel to vacuum treatment time*



11 *Vacuum in the degassing chamber in pouring of a ladle-to-ladle stream operation*

vacuum chamber during casting in the ingot mould are shown. From the diagram it can be seen that the series of values approximates very closely to Sievert's law of equilibrium, and that with an operating pressure of below 5 mm Hg the H_2 content has never been found to rise above 2·5 cm³/100 g.

DURATION OF VACUUM TREATMENT

Another factor which has a direct influence on the removal of H_2 is the duration of vacuum-degassing treatment. The data at present available are not adequate to enable well defined curves to be plotted but they are adequate to indicate that the longer the process lasts the more the residual H_2 approaches the equilibrium values. Figures 9 and 10 show the variation in H_2 content in relation to the time of vacuum-degassing treatment, but they must be regarded as only indicative. In general it can be said that with a vacuum pressure of less than 5 mm Hg the quantity of H_2 remaining falls to 1·5÷2·5 cm³/100 g. Similar results but with longer times of vacuum treatment have been obtained even when operating at higher pressures.

VACUUM TREATMENT OF STEEL FOR FOUNDRY CASTINGS OR AIR TREATMENT OF SMALL FORGING INGOTS

The process to be described differs from that previously described because in this case instead of the ingot mould, an ordinary melting-shop ladle, previously heated and dried, is placed in the vacuum chamber. When everything is ready the vacuum chamber is closed with the appropriate cover and the pumps begin operation until a vacuum of below 1 mm Hg is reached. The intermediate ladle receives the steel intended for vacuum treatment directly from the furnace and when full is placed on the top of the vacuum chamber. When it has been fixed securely in position a vacuum is created in the small antechamber between the base of the intermediate ladle and the aluminium disc. Under these conditions casting can begin.

As soon as the steel has been transferred to the ladle in the vacuum and the slag has been tapped, the vacuum is broken and the chamber reverts to atmospheric pressure but still with the teeming nozzle of the intermediate ladle left open so as to let as much slag as possible fall out into the ladle in the vacuum. This is very important as otherwise the fall in temperature will seriously jeopardize subsequent regular teeming into castings or ingots.

When casting is completed the intermediate ladle and the cover are rapidly removed and the ladle, full of steel, is carried away by crane to be cast into the ingot mould or the foundry mould. It is advisable to place under the ladle in the vacuum ladle a second ladle or an ingot mould or a feederhead capable of acting as a container in the unfortunate event of a leakage of steel from the nozzle. Furnace practice in the case of steel for vacuum treatment by the process described here is no different from normal furnace operation except for the tapping temperature. The falls in temperature are in this case greater than those occurring in direct vacuum casting into an ingot mould.

It is important to emphasize a fundamental difference between the process described here and vacuum ingot casting, particularly as regards the operation of the vacuum. It has been seen that casting began at a pressure of about 15 Torr. In the case in question the metal from the intermediate ladle is not intended to fill an ingot mould in which it is to solidify, but to fill a melting-shop ladle, and in view of the large size of the latter it is of no importance that the stream should be excessively dispersed; on the contrary, this favours the degassing process. It is therefore possible to start with very low vacuum values and keep open the connexion with the suction of the pumps (until the slag appears) for the duration of casting so as to carry out treatment with the lowest possible vacuum values compatible with the capacity of the plant. In Fig.11 a cast using the process described is shown.

The H_2 contents of the steel treated by this method are in any case also very low; unfortunately the H_2 value rises again in subsequent casting in the ingot mould or in the foundry mould but still remains much lower than at the time of leaving the furnace. The percentage reduction of H_2 is about 50–60%.

Table II gives the H_2 values of certain casts before and after vacuum treatment. It appears to confirm the conclusions previously drawn. Pressure is still constantly below 5 Torr and it seems evident that despite the very short time of treatment (5–7 min for ladles containing 30 tons of steel) the law of equilibrium is normally reached.

TABLE II H_2 values of casts before and after vacuum treatment

Cast no.	Type of steel	Pressure, Torr	Time, min	H_2 cm³/100 g Furnace	H_2 cm³/100 g S.V.
06184	Mo–V	2·9	8	4·2	2·4
E–6305	AF7 Cr–Mo	2·0	7	6·5	1·7
E–7623	AF7 Cr–Mo	2·4	3	6·9	2·5
E–7589	AF7 Cr–Mo	2·8	2 min 20 s	6·3	2·2
06405	Cr–Ni–Mo	3·7	6	3·8	1·5
06593	C	4·0	5	4·8	1·8
06476	C–V	4·5	7 min 25 s	4·7	2·0
06758	C–V	4·2	5	5·4	1·7
06156	Cr–Ni–Mo–V	3·2	6	4·2	1·6
06224	Cr–Ni–Mo	3·0	5	4·6	2·0

Non-traditional processes for iron-ore reduction

A. Scortecci and A. Palazzi

SYNOPSIS

The shortage of coking coal in Europe in recent years has claimed the attention of economists, technologists, and research workers. Of measures taken to save coke, the supply of rich ores, enrichment of lean ores, and sintering of the burden have had very favourable results. Other research is being carried out, with good prospects of success, to reduce coke consumption and replace it at least partly by other types of fuel which are not in such short supply or so valuable.

Research in the field of non-traditional reduction processes now being undertaken in many parts of the world has been given a new impulse by the shortage of coke; other research programmes have been planned and are in various stages of fulfilment. The low-shaft furnace appears today to be the only new process capable of industrial application. The processes which use electric power for thermal purposes are not at present economic. The sponge-iron reduction processes, despite the high degree of technological efficiency reached by some, still appear today far from capable of producing at costs comparable with the blast-furnace.

However, there are still various possibilities of advance which it is essential to explore. 1857

The need for new methods of extracting iron from ore

FROM 1954–56 the sustained demand for steel and the forecasts of subsequent short-term increases in demand became dominating factors in the European economy. Faced with a scrap shortage, the steel industry had to aim at the maximum possible pig-iron production which in turn resulted in a rapid increase in coke requirements. It was then that the shortage of coking coal in Europe assumed great importance because of the impossibility of mining coal at the higher rate required. To meet these requirements Europe had to import enormous quantities of coking coal from the USA and large long-term supply contracts were concluded.

In 1957 the effects of the US recession made themselves felt in Europe and the demand for steel declined; production of coal on the other hand could not be adjusted quickly enough to fluctuations in demand for iron and steel and as a result large stocks of coke were built up with serious economic and political repercussions. At the end of 1958 the market trend changed direction and the economy resumed its upward movement in 1959. In Table I world production of iron and steel is compared with ECSC production for the years 1950 to 1959 and related to coking coal consumption and coking coal imports into the ECSC during the same period.[1]

Almost the entire production of iron comes from about a thousand[2] blast-furnaces throughout the world. The blast-furnace, which has been called a 'lazy monster' ever since the beginning of the century and whose demise has been predicted many times,[3] still has no rivals in the reduction of iron ore, but there is cause for concern as to its future. The increase in iron production necessary to meet the ever-growing demand for steel, the rate at which our modern civilization is developing, and perhaps in the long view even the maintenance of present levels of production are threatened to varying degrees in different countries mainly by the shortage of coking coal.

Transport between various parts of the world of enormous quantities of ore and coke to compensate for the unbalance between established capacity and availability of raw materials has become increasingly vital. The difficult problem which the European steel industry had to solve during the period 1954–56 has stimulated much vigorous technical and economic research aimed at reducing coke consumption as far as possible and within a relatively short time the effect of this new trend has begun to make itself felt.

First there was a trend to enrich the furnace burden by abandoning lean iron ores requiring a great deal of coke and replacing them with high-grade or enriched ores which, although often costly to transport and process, permit large economies in fuel. Other possible measures which help to save coke–ore preparation range from sintering to the production of self-fluxing sinter. The order of importance in coke economy passing from lean non-sintered ore to high grade and sintered ore is shown in Fig.1, taken from Mintrop.[4]

These changes in blast-furnace practice together with the installation of increasingly large units have contributed to a gradual and substantial reduction in

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TABLE I Pig iron, steel, and coke production in the last 10 years

	Production of pig iron			Production of steel			Coke in the ECSC Blast-furnace consumption		
	World	ECSC	%	World	ECSC	%	Total	Specific average, kg/ton	Imports of coking coal, tons
1950	133000	26138	19·53	189000	31753	16·78			
1951	150000	31396	20·90	210000	37706	17·94			
1952	150000	34784	23·12	210000	41765	19·87			
1953	167000	31541	18·80	236500	39651	16·77			
1954	156000	33213	21·29	224000	43835	19·56	31799	957	2542
1955	190000	41138	21·59	270400	52580	19·45	39806	967	5350
1956	198000	43583	21·96	284000	56720	19·97	42227	969	9546
1957	208000	45115	21·63	293100	59803	20·40	43854	972	9509
1958	190000	43525	22·91	272500	57945	21·26	41299	949	7453
1959	202000*	46671	23·10	297500*	63146	21·23	41084†	880	5523†

* *Steel*, 1960, 4 Jan. † Calculated by extrapolation from the figures for the first eight months of 1959.

coke consumption, as shown in Fig.2 extracted from the ECE report for 1959.[5] In addition, the change in the sources of raw material supplies continues to influence the iron and steel industry in another direction which is very significant economically; new steelworks now tend to be built on coastal sites to save unloading costs and particularly land transport. Long-distance sea transport of ore and coke is becoming a more widespread and specialized branch of the industry.[6] This development helps to lessen the difference in production costs between countries rich in raw materials and those less fortunate in this respect.

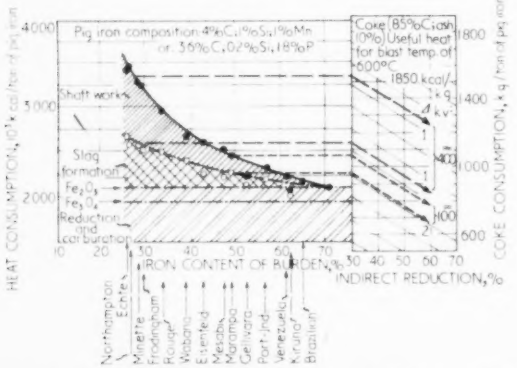
It is therefore possible that the coke shortage which at present appears the greatest obstacle to the development of steel production in Europe may in the future lead to profound changes in the primary iron and steelmaking processes.

Other measures still midway between practical application and the research stage, include the use of high top-pressure, the use of air with controlled humidity, increase in blast temperature, and oxygen enrichment of blast, replacement of part of the coke by liquid or gaseous hydrocarbons, and blowing in powdered coal.

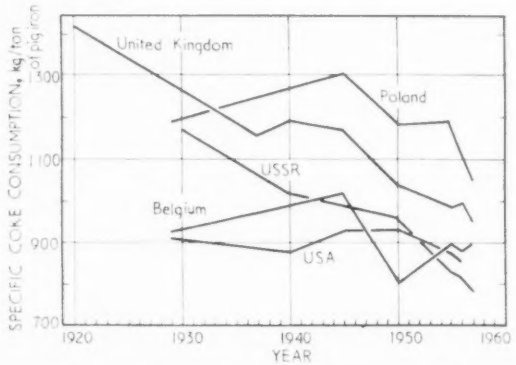
In addition to direct methods of reducing coke consumption there is also research aimed at making metallurgical coke from poorer quality coal and some progress has been made in this field, e.g. (increased density of charge materials, selection of petrographic constituents, and development of synthetic mixtures) Thus while technologists and scientists are carrying out research and taking steps to improve the technique and economy of pig-iron production in the blast-furnace, another perhaps even more numerous contingent is engaged throughout the world in trying various methods to achieve a radical solution of the problem: most of these efforts aim at obtaining iron directly from ore and in some cases at producing semi-finished products.

As a result the large steel companies throughout the world are continually initiating new research and planning future research programmes with this in mind. In addition to the innumerable projects and preliminary laboratory experiments much progress has been made with pilot plants and even small industrial plants where local conditions have been favourable. Over 1000 patents have been registered for new processes. Even the USA, which has certainly not at present any shortage of coking coal, has felt the need to try new ways of extracting iron from ore. It is estimated that the US steel companies alone are spending $10–20 m. a year on continuing old and starting new research in this field.[7]

The term 'direct reduction processes' often used applies strictly speaking to those processes which reduce directly to iron (sponge iron), or to low-carbon steel, but it is customary to include these among the 'non-traditional processes' as well as those aiming at producing a more or less carbonized liquid product, when this is not performed by the traditional blast-furnace process; among these are processes which, industrially speaking, are very advanced. These include the electric reduction furnace and the low-shaft furnace, both of which to a certain extent mark a transition from the traditional processes to more revolutionary solutions.



1 *Influence of iron content and sintering increase on specific coke consumption in blast-furnace*



2 *Specific coke consumption in various countries and its trend, 1920–57*

TABLE II Influence of temperature on gaseous reduction Time to achieve 90% reduction for cubes of Fe_2O_3 and Fe_3O_4 of 14 mm size

Temperature, °C	Reducing gas Hydrogen Time, min	Carbon monoxide
600	111	...
700	42	...
800	26	...
1000	15	61

However, whereas the measures aimed at lowering coke consumption in the blast-furnace have already led to concrete results and there are good prospects of successful partial replacement of coke in the blast-furnace by fuel-oil and various gases, none of the new processes has yet achieved satisfactory economic results when compared with the traditional process.

Considering all these processes and indicating the most probable future of the new methods, assumptions must be made regarding the future of the iron and steel industry itself.

New processes and the physical chemistry of reduction reactions

The reduction agents of practical importance are essentially carbon, carbon monoxide, hydrogen and their mixtures.

To illustrate better the technical and economic possibilities of the new processes it will be useful to summarize the essential information derived from the physical chemistry of the reduction reactions of the iron oxides (*see* Appendix):

(i) the reduction reactions of the iron oxides of all kinds are endothermic for carbon and hydrogen and exothermic for carbon monoxide

(ii) diagrams which express the equilibrium conditions of reduction reactions as a function of the temperature show that the hydrogen curve and the carbon monoxide curve intersect at 810°C; above this temperature the equilibrium ratio of reducer/reaction product indicates that hydrogen is more effective whereas below it carbon monoxide is more effective.

A great degree of uncertainty still surrounds the kinetics of these reactions and in contrast to the situation shown for the equilibrium it is commonly accepted that the effectiveness of the reducers can be reversed. Operating with extreme excess of reducer, far from the equilibrium, at relatively low temperatures (up to about 900°C) the hydrogen seems to be more active than the carbon monoxide, whereas at higher temperatures the contrary is true.[8] In general the speed of reduction increases as the temperature and the pressure increases; it falls, however, as the reducing gas diffuses into an inert atmosphere (presence of nitrogen) or one polluted by the reaction products (presence of CO_2 and H_2O).[9] Some figures on the kinetics of these reactions, taken from Tenenbaum and Joseph,[9] are given in Tables II and III; the degree of reduction is expressed in the ratio of oxygen removed/total oxygen.

The flow of reducing gas seems to have a great influence.[10] This must certainly be finally attributed to the extremely high local excess of reducer in the area where reduction is taking place. At 850°C with

TABLE III Influence of pressure on gaseous reduction Time to achieve a reduction of 90% at 1000°C

Reducing gas	Pressure 1 atm Time, min	2 atm
Hydrogen	15	9
Carbon monoxide	61	47
Mixture 35%CO, 65%N_2	118	94
BF gas 28·4%CO, 8·2%CO_2	190	236

gas of analysis 7·3%CO_2, 32·1%CO, and 60·6%N_2, and with gas rates of 1·30 m/s and 6·30 m/s, the total time of reduction was 430 min and 86 min. This result has been confirmed by reducibility tests carried out at the Istituto Siderurgico Finsider with increasing flow of hydrogen.[11] Results of the reduction tests at 900°C on 4–6 mm fraction Ouenza ore are given in Fig.3. The form of the reducibility curves shows that the rate at which oxygen is removed falls strikingly as reduction proceeds. Thus from curve 4 in Fig.3 it is seen that it takes 5 min to remove 10 units of oxygen from 0 to 10% degree of reduction whereas 25 min are needed to move from 85 to 95%.

Although the kinetics of the gaseous reduction process is an extremely complex phenomenon the conventional reducibility test certainly offers a semi-quantitative model of its progress.

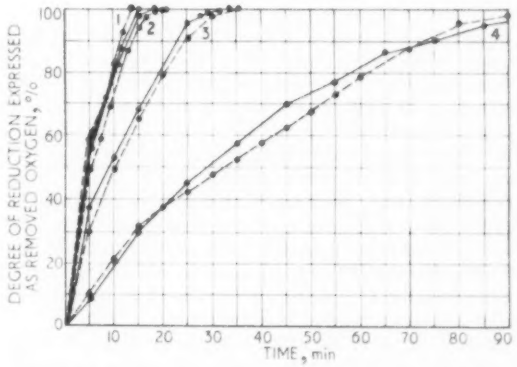
New processes compared with blast-furnace

With coke economy remaining the principal reason for research into various reduction processes different from the blast-furnace the non-traditional processes have certain advantages and disadvantages which must be described and assessed.

Advantages

Possibility of avoiding costly investments

The blast-furnace requires heavy capital expenditure even for the installation of medium-size units, while smaller units cannot be constructed as they involve prohibitive costs in production. One factor is that many companies or countries only need to produce limited quantities of steel and are looking for less costly methods (not necessarily exclusively blast-furnace plant) which can provide iron at costs comparable with the traditional process allowing independence from the scrap market.



H_2: *1* 2750 l./h *2* 2000 l./h *3* 1250 l./h *4* 500 l./h

3 *Reducibility tests with increasing hydrogen flow rates*

Production of high-quality 'artificial scrap'
A certain number of direct reduction processes produce a solid 'sponge iron' which is a kind of 'artificial scrap'. Wherever scrap is scarce or costly such material finds a ready market. Specific uses of directly reduced material are, first, charging into the blast-furnace when the material obtained is still full of impurities or has a low degree of reduction (Krupp Renn and RN). This is undoubtedly one of the most advanced measures taken to reduce coke consumption. Second, there is the more or less complete replacement of scrap by sponge iron in the burdens of electric or OH furnaces producing high-quality steels from a solid charge.

It is known that gradually the scrap is enriched by nobler elements than iron such as copper, nickel, chrome, tin, etc., usually because of unavoidable pollution by motor industry scrap. This is a great problem in the production of high-purity steels.

Sponge produced by the Wiberg process is a typical example of high-quality artificial scrap for premium steel production (particularly bearings). Its cost can compete with that of steel produced several decades ago from pure pig irons made from charcoal.

Complete substitution of other fuel for coke
In its more ambitious applications direct reduction aims at the complete replacement of coke by gas derived from the conversion of gaseous hydrocarbons (e.g. natural, producer, and coke-oven gas), by fuel oil, and sometimes even by natural solid fuels of a low quality.

This possibility should encourage the growth of steel industries of limited size in under-industrialized countries without the need for installation of large coke-oven plants.

Use of powdered concentrates or non-prepared ores
Certain processes enable ores to be used with a very large size range or powdered ores which, if otherwise processed, particularly in the blast-furnace, would have to be sintered; ore preparation in these cases is not necessary.

Disadvantages

The new processes have many disadvantages compared with the blast-furnace, particularly those with a solid end product. The possibility of avoiding or reducing these disadvantages provides a wide field for research.

Frequent need of processing rich ore
The main disadvantage of processes which do not pass through a liquid state is that all constituents accompanying the iron oxides remain in the sponge. To obtain iron of sufficient purity it is essential to use high-grade ores and above all enriched ores, as the former are almost exclusively used for refining in the liquid pig iron-ore process. Figure 4 taken from Tigerschiöld and Eketorp[12] shows the relationship between the composition of the ore (magnetite and hematite) and that of sponge after reduction to 96, 90, and 40% by the Wiberg process. In remelting in the electric furnace 1% of gangue involves an increase in energy consumption of 6 kWh per ton of steel.

Attempts to enrich sponge iron after reduction have had negative or at best very doubtful results, as sponge with a high degree of reduction is very plastic and as a result grinding is difficult and costly. If the original ore is difficult to enrich as a result of the difficulty of attaining a high degree of liberation (sometimes fine grinding of powder down to several microns might be necessary) the problem persists and becomes even more intractable after reduction to sponge.

Low rate of reduction
Direct reduction to produce a solid product takes place at relatively low temperatures of between 600° and 1000°C according to the various processes.

According to kinetic considerations the problem (confirmed by experience) is that the reduction takes a considerable time, particularly for high rates of reduction. Whereas the maximum temperature in the blast-furnace is found in the zone of maximum reduction and fusion of the product, in the direct-reduction processes producing a solid product the maximum temperature is often attained in another part of the installation, e.g. in the reducer gas-generator. Certain direct reduction processes require very long reaction times as, for example, the Höganäs process which takes about 180 h.

On the other hand remelting of sponge of a low degree of reduction in an electric steel furnace involves greater consumption of electricity. Every unit of oxygen present in the material requires additional power amounting to 33 kWh per ton of steel produced.[12]

Frequent pyrophoria of the product
Also related to the low reaction temperature are difficulties with regard to the pyrophoria of the product resulting from certain gaseous reduction processes; this property is a serious problem in mass production. We are not referring here to hot pyrophoria as all hot sponge irons are pyrophoric at high temperatures but to pyrophoria at room temperatures with sponges produced at temperatures below 700°C. Here the product ignites as soon as it is exposed to air and can cause serious accidents. Thus the sponge obtained by the process must be compacted in a hydrogen atmosphere and conserved in oil to avoid spontaneous combustion.

At temperatures exceeding 700°C the coalescence of the reduced particles begins to be considerable and the phenomenon disappears. A sponge treated at 1000°C is stable.

Need to operate with excess of reducer
To reduce at an industrially acceptable rate it is necessary to operate with a large excess of reducer and this means finding a good use for the outgas which still has a very high chemical potential.

For this reason almost all direct-reduction processes producing a solid product and using a gaseous reducer, recycle the gas after previously eliminating oxidized constituents. Many methods provide for preheating and pre-reduction of the charge using a proportion of the outgases. In the recycling processes the gas cannot of course contain nitrogen, the content of which would increase continually; to prevent this many processes use gaseous reducers obtained by converting fuels with oxygen and from the economic point of view they are tied to the industrial future of oxygen.

Tendency to sticking
The charged materials after preheating or after reduction tend to agglomerate and stick to the walls. It will

be remembered, for example, that the eutectic of the ternary system FeO–SiO_2–Al_2O_3 already melts at 1088°C and that many silicates melt into extremely viscous liquids. This has very serious practical consequences for many direct reduction processes.

Limitations due to the consumption of large amounts of electricity

This limitation applies to many new processes producing either a liquid or solid product. According to authoritative estimates there will soon be a shortage of electric power in Western Europe. It is therefore very valuable and priority in its use should be given to processes other than the creation of heat for iron and steelmaking. For mass production all processes must therefore be excluded which require electricity. It is clear that discoveries which substantially increase the availability of such energy will lead to a re-examination of the entire question particularly as the electric reduction furnace is today being considered an extremely advanced process.

Classification of the principal new processes for the reduction of iron

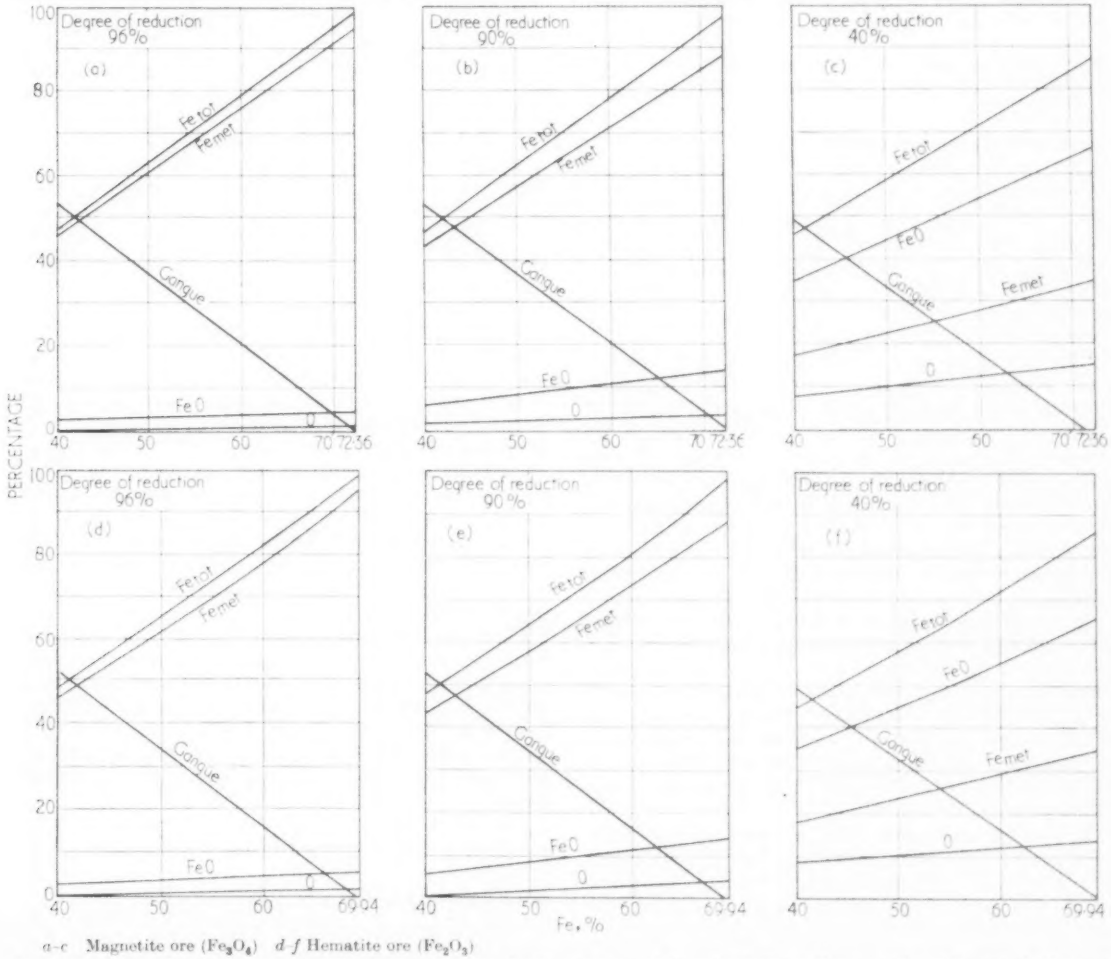
The criteria for classification may vary according to:

(i) type of product (liquid or solid)
(ii) grade of ore (poor, rich, etc).
(iii) size of ore (sized or powdered)
(iv) type of fuel (gaseous, liquid, or solid)
(v) type of reaction vessel (shaft-furnace, rotary kiln, fluidized bed, etc.)

It seems that the main criterion for (i) should be the type of final product; liquid (iron or steel) or solid (sponge iron) since the metal is further refined by quite different technical and economic processes in each case.

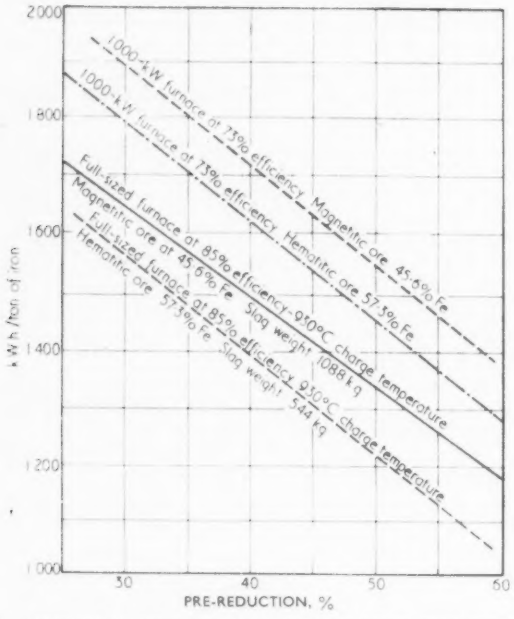
In the first case there may be an excess of carbon, in the second gangue and oxides not completely reduced in the sponge are quite likely to be present in the product. The second selective factor is the state of the reducer used (gaseous or solid); the third is the type of reaction vessel (shaft, etc.).

This classification is given in Table IV and contains almost all the processes developed. The Krupp Renn process marks the transition between the processes in the first two main categories. This process because of the partial separation of the phases has resulted in a product of very high metallic iron content although based on lean ore and can be included in the liquid product classification.



a–c Magnetite ore (Fe_3O_4) *d–f* Hematite ore (Fe_2O_3)

4 *Composition of sponge iron at different degrees of reduction (expressed by ratio* $\%Fe_{met}/Fe_{tot}$*) made with ores of different iron contents*



5 *Relationship between estimated electric power consumption and pre-reduction degree in some applications of the Strategic Udy process*

TABLE IV Classification of the non-traditional processes for the reduction of iron ore

Product	Reducer	Reaction vessel
Liquid	Solid	Shaft furnace Electric furnace Rotary kiln
	Gaseous	Cyclone
Solid	Solid	Tunnel Rotary kiln
	Gaseous	Shaft furnace Rotary kiln Travelling grate Fluidized bed

Processes with liquid end product

Typical data for these processes are given in Table V. In view of the big differences in the stage of development which these various processes have reached, ranging from the industrial plant for which detailed operating data are known and available (Tysland Hole, Krupp Renn) to a simple description (flame smelting). Special marks are given to specify the data available according to reliability.

The first of the processes given in Table V, the low-shaft furnace, is a type of plant several of which are operating on a semi-industrial or industrial scale.

The characteristics of the low-shaft furnace are oxygen enrichment of the blast, possibility of using various unusual types of coke, adding liquid or gaseous hydrocarbons and operating with top pressure. The figures given for the low-shaft furnace in Table V relate to the international plant at Liège where, using top pressure and a 100% self-fluxing sinter burden, interesting preliminary results have been obtained.

A detailed description of the low-shaft furnace is given later (p.275). Many of the processes producing a liquid final product are carried out in the electric furnace and in many cases (Elektro Kemisk, Strategic Udy, Dwight Lloyd McWane) involve pre-reduction of the burden (*see* Fig.5)[13] to reduce the consumption of electricity by the reduction process. This process can be considered in its usual form almost as a traditional process (Tysland Hole).

It can be estimated that a medium-size blast-furnace consumes about 5500 Mcal per ton of pig iron, in the form of coke (of which 20% is available as excess top gas); a medium-size electric furnace consumes about 4800 Mcal of coke and electricity per ton of pig iron but in most cases no gas recovery is practised. But today electricity is still too costly to be used for the mass-production of pig iron. The electric reduction furnace therefore has only a limited and often seasonal application generally for the production of ferroalloys.

The difficulty of processing highly conductive burdens in the electric reduction furnace (the pre-reduced ore) seems to have been overcome (Strategic Udy) by using electrodes submerged in the slag which thus becomes the heating resistance; the Lubatti and Elektrofliessreduktion often also use a similar heating system.

Some of the processes by which liquid pig iron is produced in rotary kilns are highly developed, e.g. Stürzelberg and Basset (the latter at the same time produces fused cement). But they are big fuel consumers and can only operate economically in special circumstances; others (Azincourt) have not yet passed the small experimental or pilot-plant stage.

The De Sy process can only use very pure materials. This process is carried out in an electric-induction furnace divided into two parts which enable coal and ore to be charged separately and directly into the molten bath. Adequate figures are not yet available to draw conclusions as to the possibility of applying this method on an industrial scale.

The Krupp Renn process occupies a special position and there are many industrial plants now operating. The Krupp Renn process achieves the partial melting of iron and the complete melting of the gangue. By magnetic separation iron nodules are obtained for the blast-furnace burden and often steel furnace charge (depending on the sulphur content) from the cooled and ground product. The process requires highly siliceous ores which are quite unsuitable for the blast-furnace and for many other new processes. But the total fuel consumption is very high although the high cost is somewhat reduced by the fact that poorer quality coal can be used.

Processes based on 'cyclone' smelting (jet smelting, flame smelting) are convincing in theory. Coal, ore and oxygen react in a single vessel to produce liquid steel but these processes, as far as we know, have not yet passed the laboratory stage mainly because of difficulties connected with the high operating temperatures and particularly the slag attack on the refractories.

We believe it would be premature today to draw conclusions regarding their future development.

Non-traditional processes with solid end product

The characteristic data for these processes are given in Table VI. Table VII gives for the same processes the characteristics of the material produced and an estimate of the additional energy consumption necessary

TABLE V Known characteristics of reduction processes with a liquid end product

Category	Description	Product	Consumption per ton of product: Coke or semi-coke, tons	Other coals, tons	Liquid fuel, kg	Electric power, kWh	Estimated total,* Mcal	Oxygen, m^3	Ore, tons	Limestone, tons	Electrodes, kg	Type of plant	Classification of data	Ref. no.
Solid reducers														
Shaft furnaces	Low-shaft furnace†	pig iron	0·830	—	70	x	5700	130	x	—	—	P	A	19
Electric furnaces	Tysland Hole	pig iron	x	0·400	x	2400	4865	—	x	x	15–20	I	A	20
	Elektrokemisk	pig iron	x	0·390‡	—	1400	4325	—	x	x	8	P	A	21
	Strategic Udy	pig iron or steel	—	0·430‡	—	1138	3987	—	1·770	0·500	15	I	C	22
	Dwight Lloyd McWane	pig iron	x	x	x	x	x	—	x	x	x	L	x	23
	De Sy	pig iron		0·350	—	1830	4025	—	x	x	x	P	A	24
	Laluatti	pig iron	0·375	0·382	—	3225	8074	—	x	x	x	I	A	25
	Elektrofluss Reduktionsofen	pig iron	x	—	—	2500	x	—	x	x	x	x	C	26
Rotary kiln	Basset	pig iron	0·610		330	100	7656	—	1·490	0·340	—	I	C	27
	Stürzelberg	pig iron	0·980	0·680	—	x	11620	—	x	x	—	I	A	28
	Azincourt	pig iron		0·800	200	100	7686	—	x	x	—	P	C	29
	Krupp Renn	nodules	0·935	0·232	—	75	8234	—	3·568	—	—	I	A	30
Gaseous reducers														
Cyclone	Jet smelting	steel	x	x	x	x	x	—	x	x	—	x	x	31
	Flame smelting	steel	x	x	x	x	x	—	x	x	—	P	x	32

* For estimating total energy consumption the following heat values were used: coke and coal 7000 kcal/kg; liquid fuel, 10000 kcal/kg.
† Operation with 100% self-fluxing agglomerate and top pressure (1·5 kg/cm²).
‡ Fixed carbon 8000 kcal/kg. § Ore, 35% Fe.
I industrial, P pilot, L laboratory, C calculated, A actual, x not available, — not used.

to transform the sponge iron into steel in the electric furnace.

Depending on the iron content of the ore used and the degree of reduction attained the direct reduction processes can produce iron powder for sintering, artificial scrap, or pre-reduced material for charging into the blast-furnace. The processes which produce iron powder (Höganäs, ORF Direct Steel) require high iron content ore, usually enriched magnetite and attain degrees of reduction close to 100%. The Höganäs process is an industrial process for the preparation of material suitable for powder metallurgy; ore concentrates and charcoal are heated in containers and after several days of processing in the tunnel kiln reduction is complete. The Direct Steel process is at an early stage of development; it is hoped by complete reduction of super-concentrate on a travelling grate to obtain material for hot rolling of semi-finished products, plates, and sections.

The majority of the processes using solid fuels use rotary kiln furnaces (RN, Krupp Renn Sponge, Kalling Domnarfvet, Kalling Avesta, Laramie) and some of them are restricted by the great difficulty of separating the metallic iron from the gangue. In the RN process the enrichment of the sponge is carried out in a dozen stages of magnetic separation. The results differ according to the type of ore used. The production of material reduced 60–70% using lean ore which cannot be charged directly into the blast-furnace is also considered useful. In general a direct reduction process can be expected to produce material for the blast-furnace; if the object is to reduce coke consumption this can be achieved by using partially metallic burdens; total energy consumption may be greater but a large proportion of energy is derived from coals of low coking quality.

In the rotary kiln furnaces reduction processes can be carried out using gaseous agents; in the Finsider I process, developed as a pilot plant, hydrogen, from cracking natural gas has been used experimentally as a reducer. It was possible to produce highly reduced sponge. The recycling of the gases has been planned but not yet carried out experimentally. Trials have been held up because of the scarcity of natural gas which has been diverted to more urgent needs.

Reduction processes using gaseous agents which do not contain inactive constituents (notably nitrogen from the air) enable the final gases to be recycled, and this is the device which enables fuel consumption to be reduced substantially. From what has been said in the previous chapters gas reduction is performed with very low efficiency; if the outgoing gases are purified in some way from the reaction products (water and carbon dioxide) these may still be used for reduction and consumption can approach the stoichiometric value; this method has been considered or actually used in many processes of this type.

Naturally low consumption of reagents does not necessarily imply minimum costs; hence the Wiberg process, one of the more firmly established in this category, consumes a total of 2160 Mcal per ton of sponge but purifies the outgoing gases in an electric carburettor which uses about 900 kWh/ton of sponge produced. In view of the cost of electric power the process has only been applied on an industrial scale in Sweden where the cost of electric power is very low. The sponge is, however, used for special products where

TABLE VI Main characteristics of reduction processes with a solid end product

Category	Name	Consumption per ton of product: Coke or semi-coke, tons	Other coals, tons	Liquid fuels, Mcal	Natural gas, Nm³	Electric power, kWh	Total estimated,* Mcal	Oxygen, Nm³	Ore, tons	Limestone, tons	Electrodes, kg	Recycling	Type of plant	Classification of figures	Ref. no.
Solid reducers															
Tunnel kiln	Höganas	—	0·570	920	—	75	4974	—	1·5	0·120	—	G	I	A	33
Rotary kiln	RN	—	0·385	2004	—	145	4824	—	1·75	0·080	—	G	P	C	34
	Krupp Renn (sponge)	x	x	x	x	x	—	—	x	—	—	G	P	x	35
	Kalling Domnarfvet	—	**0·650**	—	—	x	—	—	x	—	—	G	P	A	36
	Kalling Avesta	—	**0·530**	—	—	**1000**	**4570**	—	x	—	x	G	P	A	37
	Laramie	—	**0·670**	—	—	x	—	—	x	—	—	G	P	A	38
Gaseous reducers															
Shaft furnaces	Wiberg	0·115	—	600	—	900	2160	—	1·31	0·080	1·5	R	I	A	39
	Hoyalata y Lamina	—	—	—	652	70	5602	—	x	—	—	G	I	A	40
	Norwegian H iron	—	—	—	750†	1690	3280	—	x	—	—	R	x	C	41
	Norsk Staal	0·220	—	—	115‡	1510	3300	—	x	0·06	x	R	P	A	42
	Finsider II‖	0·140	—	—	115	1108	2052	195	x	—	—	R	P	C	43
	Lurgi Gallueser	—	—	—	200	1090	2560	x	x	—	—	R	P	C	44
	Madaras	—	—	—	520	60	4472	—	x	—	—	R	P	C	45
Rotary kiln furnace	Finsider I••	—	—	—	665	x	5652	—	x	—	—	G	P	C	46
Travelling grate	ORF Dir. Steel Pr.	x	x	x	x	x	—	x	x	—	—	R	P	x	47
Fluidized bed	Nu Iron (US Steel)	x	x	x	**170**	x	—	—	x	—	—	R	P	C	**48**
	Esso AD Little	—	—	—	415	x	3527	—	x	—	—	G	P	C	49
	H-iron	—	—	—	**470**	**110**	**4090**	—	x	—	—	R	P	C	50
	Onia Novalfer	x	x	x	x	x	—	x	x	—	—	R	P	x	51
	Fe–C–CO Verfahren	**0·600**	—	x	—	—	—	**500**	x	—	—	R	L	C	52
	Stelling	0·204	—	—	—	x	—	—	1·29	—	x	R	P	C	53

Consumption figures in bold type relate to a ton of metallic iron.
• For estimating energy consumption the following heat values were used: coke and coal, 7000 kcal/kg; natural gas 8500 kcal/Nm³
† Gas at 2300 kcal/Nm³. ‡ Coke oven gas valued at 4000 kcal/Nm³. § Electric power required for the production of oxygen.
‖ Estimates from projected pilot plant under construction at Istituto Siderurgico Finsider with financial assistance from the ECSC.
•• Trials at pilot-plant stage interrupted because of substantial fluctuations in the availability and price of natural gas in Italy.
I industrial, P pilot, L laboratory, C calculated, A actual, R recycling of gas carried out, G credit for gas used for thermal purposes, x not available, – not used.

freedom from impurities is essential and it is therefore inadvisable to use scrap of uncertain origin or charge materials which have not been carefully checked.

Another method of regenerating outgoing gases is by chemical purification as envisaged in the Finsider II project, the characteristics of which are the use of blast, a gas produced in a gas-slagging generator with oxygen and the separation of pre-reduction from reduction. This process, carried out on a small scale in separate stages, is now being developed in a pilot plant with financial assistance from the ECSC. The recycling of outgoing gases is also possible in many other reduction processes which are carried out on fluidized beds (H-iron, Onia Novalfer, Nu Iron, Stelling Fe–C–CO process). In the case of the H-iron process the purification of the gases made up initially of pure hydrogen is very simple; it is sufficient to cool under pressure and condense the water.

For all processes carried on fluidized beds and followed by purification and recycling of gas the reducer gas must be obtained by converting fuels with oxygen; if the use of oxygen is not practical, e.g. in under-industrialized areas gas converted by air can also be used (Esso AD Little process) but in this case the outgoing gas cannot be recycled and can only be used as fuel.

The Hojalata y Lamina and Madaras processes use the outgoing gases as fuel. The first process is being applied in Mexico under extremely favourable conditions due to the existence of high-grade ore and abundant natural gas which is far beyond local needs.

Unless it is thought sufficient to produce low-quality material to use as burden to be processed further in a subsequent unit, the fluidized bed processes must also use exclusively high-grade or enriched ores. If it is considered that 80% of the particles more frequently used for fluidizing range between ¼ and 4 mm and that in any case it is difficult to process in a fluidized bed concentrates which are all less than 0·1 mm it is evident that the use of enriched ores, for which crushing to 200 mesh is often necessary, is out of the question unless micro-agglomeration with controlled outgoing particle size is carried out; this has not been tried up to the present.

A few years ago all direct reduction processes faced this difficulty. However, as a result of the industrialization of magnetic concentration processes, followed by pelletization or sintering, the production of enriched ore has become an economic proposition. This is an excellent basic material for all those processes in which the burden is static or almost static but it cannot be used in rotary kilns or in fluidized beds.

The H-iron process and in general many fluidizing processes operating at low and medium temperatures also produce very pyrophoric material which is difficult to handle and stock, and costly counter-measures are necessary (e.g. rolling under hydrogen atmosphere and conservation in oil). In addition, up to the present operating fluidized beds at high temperatures seems to be ruled out because of the tendency of the particles to sinter, making it impossible to maintain the fluidized bed. Certain processes (for example Fe–C–CO, Norwegian Ferro H, Onia Novalfer) are still in the trial and development stage.

Some processes (Norsk Staal, Laramie, Kalling Avesta) have been abandoned as soon as the results of pilot-plant tests have shown them to be unsatisfactory.

TABLE VII Characteristics of sponge iron produced by the processes in Table VI. Use of sponge in steelworks

Category	Name	Fe_{tot} in ore, %	Sponge		Degree of reduction, $\%Fe_{met}/Fe_{tot}$	Factor for estimating consumption per ton Fe_{met}	Estimated additional consumption for steelmaking*		
			Fe total, %	Fe_{met}, %			Electric power, kWh	Coal,† kg	Total, Mcal
Solid reducers									
Tunnel kiln	Höganäs	71·3	97	93	96	1·075	49	9	105
Rotary kiln	RN	56·0	93	88	94·6	1·136	81	10	140
	Krupp Renn sponge	x	90	76·5	85	–	–	–	–
	Kalling Domnarfvet	55·4	91·8	83	90·3	1·000	–	–	–
	Kalling Avesta	60–65	94·5	88	93	1·000	84	14	170
	Laramie	x	91	75	82·4	1·066	–	–	–
Gaseous reducers									
Shaft furnaces	Wiberg	66	86·0	77	89·5	1·299	154	19	265
	Hoyalata y Lamina	66	91	85·4	93·8	1·171	98	11	161
	Norwegian H iron	x	93·8	x	–	–	–	–	–
	Norsk Staal	68	93	85·1	91·5	1·175	104	17	208
	Finsider II	62	90	81	90	1·235	130	19	245
	Lurgi Galluser	x	x	x	85	–	–	–	–
	Madaras	x	94·7	92·8	98	1·078	47	3	61
Rotary kiln	Finsider I	x	81	76	94	1·316	153	8	188
Travelling grate	ORF Dir. Steel Pr.	⩾72	x	x	x	–	–	–	–
Fluidized bed	Nu Iron	x	x	x	x	–	–	–	–
	Esso AD Little	64·5	95	x	x	–	–	–	–
	H-iron	x	x	x	x	–	–	–	–
	Onia Noval	x	x	x	x	–	–	–	–
	Fe–C–CO process	x	x	x	x	–	–	–	–
	Stelling	62	80	69·6	87	1·437	–	–	–

* Estimate of additional consumption for steelmaking only takes into account the energy needed for the reduction of the residual iron oxide and for the melting of the gangue. It has been calculated on the basis of the two equations (Tigerschiold–Ekeforp, *Metallurgia*, 1948, **37**, 167.)

(i) $33{\cdot}27.O_2.6{\cdot}00$ GkWh/ton of sponge iron

(ii) $8{\cdot}02.O_2.\ 0{\cdot}176.G$kg carbon/ton of sponge.

where O_2 and G represent respectively the percentage of oxygen and gangue in the sponge iron.

† The heat value of carbon was stated in 7000 kcal/kg. x Not available. – Not used.

The special position of the low-shaft furnace

Among the new reduction processes reviewed, the one which seems to be best qualified to be compared technically and economically with the blast-furnace is without doubt the low-shaft furnace. Tests carried out on a large scale with various units in different countries particularly at Ougrée-Marihaye in Belgium, initiated by an International Committee in 1951 under the auspices of the OEEC and today developed by the Technical Research Committee of the ECSC with special funds, have shown that pig iron can be produced at costs which compare with the blast-furnace.[14]

It has been recognized that the low-shaft furnace can use low-quality and small-size coke and small-size ore which cannot be used in blast-furnaces; methods of enriching the blast with oxygen, increasing top-pressure, and injecting fuel oil have been tried out with favourable results. Trials are far from complete and various methods of improving the process remain to be tried.

The low-shaft furnace requires the same order of specific capital investment as the blast-furnace. Perhaps this process is today the only one which will enable a small or medium-sized firm or possibly a small country, which could not afford the high capital expenditure needed for blast-furnaces, to produce pig iron at a cost close to that of blast-furnace pig iron. Supplies of raw material are more easily obtainable than those for the blast-furnace, especially coke, and independence from the fluctuations of the scrap market is assured.

The International Blast Furnace Committee operating within the ECSC research board has drawn attention in the trial research programmes to the possibility of using the low-shaft furnace as an experimental blast-furnace. From this point of view the low-shaft furnace has recently supplied a great deal of very valuable information for the better understanding of blast-furnace operation. From the results obtained it is possible to foresee new lines of advance.

For instance, the requirement that air blown in through the tuyeres may reach the centre of the burden column imposes a maximum capacity limit which seems to be about 2000 tons/24 h. In theory the low-shaft furnace could be developed into narrow units elongated to an unlimited extent. This would enable very large units to be constructed capable of consuming the same low-quality raw materials used successfully in the experimental low-shaft furnace.

CONCLUSIONS

A summary of the various processes for extracting iron from ores confirms that at present the production of pig iron in the blast-furnace is by far the best and most convenient process for mass production.

The increased demand for pig iron in recent years has revealed a scarcity of coke and it appears inevitable that the shortage will recur and become worse in the future.

Much has been done and remains to be done to improve blast-furnace practice, particularly in lowering specific coke consumption. Among the steps already taken to achieve this, and those still in the research stage, are in order of importance: increase in the iron content of the burden, sintering of ores, superheating of the blast, high top-pressure, oxygen-enriched blast, and simultaneous injection of fuel oil or natural gases.

Among the new processes the only one which has proved itself on a large scale and which is suitable for a variety of circumstances is without doubt the low-shaft furnace for which an interesting future may be predicted. All the other processes are much less practicable and suffer from limitations which rule them out

TABLE VIII Gibbs free energy for the reduction of ferrous oxides at atmospheric pressure

Reduction reaction	$G°_T$, cal/mol	Temperature at which $G°_T$ is negative
$3Fe_2O_3+CO=2Fe_3O_4+CO_2$	$-7900-12{\cdot}9T$	Any temp.
$3Fe_2O_3+H_2=2Fe_3O_4+H_2O_v$	$600-20{\cdot}2T$	Almost any temp.
$3Fe_2O_3+C=2Fe_3O_4+CO$	$32900-54{\cdot}6T$	$T>600°K$
$6Fe_2O_3+C=4Fe_3O_4+CO_2$	$25000-67{\cdot}5T$	$T>370°K$
$Fe_2O_3+CO=2FeO+CO_2$	$2100-10{\cdot}4T$	Practically any temp.
$Fe_2O_3+H_2=2FeO+H_2O_v$	$10200-17{\cdot}8T$	$T>600°K$
$Fe_2O_3+C=2FeO+CO$	$42900-52{\cdot}1T$	$T>820°K$
$2Fe_2O_3+C=4FeO+CO_2$	$45000-62{\cdot}5T$	$T>720°K$
$Fe_2O_3+3CO=2Fe+3CO_2$	$-8900+1{\cdot}2T$	Practically any temp.
$Fe_2O_3+3H_2=2Fe+3H_2O_v$	$16300-21{\cdot}0T$	$T>800°K$
$Fe_2O_3+3C=2Fe+3CO$	$113700-123{\cdot}9T$	$T>920°K$
$2Fe_2O_3+3C=4Fe+3CO_2$	$104800-122{\cdot}7T$	$T>850°K$
$Fe_3O_4+CO=3FeO+CO_2$	$7100-9{\cdot}1T$	$T>780°K$
$Fe_3O_4+H_2=3FeO+H_2O_v$	$15600-16{\cdot}5T$	$T>940°K$
$Fe_3O_4+C=3FeO+CO$	$47900-50{\cdot}9T$	$T>940°K$
$2Fe_3O_4+C=6FeO+CO_2$	$55000-60{\cdot}0T$	$T>910°K$
$Fe_3O_4+4CO=3Fe+4CO_2$	$-9400+8{\cdot}2T$	$T<1140°K$
$Fe_3O_4+4H_2=3Fe+4H_2O_v$	$24800-21{\cdot}3T$	$T>1160°K$
$Fe_3O_4+4C=3Fe+4CO$	$154000-158{\cdot}6T$	$T>980°K$
$Fe_3O_4+2C=3Fe+2CO_2$	$72400-72{\cdot}2T$	$T>960°K$
$FeO+CO=Fe+CO_2$	$-5500+5{\cdot}8T$	$T<960°K$
$FeO+H_2=Fe+H_2O_v$	$3000-1{\cdot}6T$	$T>1870°K$
$FeO+C=Fe+CO$	$35350-35{\cdot}9T$	$T>1000°K$
$2FeO+C=2Fe+CO_2$	$29850-30{\cdot}1T$	$T>1000°K$

in competition with the blast-furnace; at best they are suitable only for special local conditions. Processes of this kind are:

(i) those using electricity as a source of heat. Although in certain cases these have attained a high degree of technological development (Tysland Hole, Wiberg) they cannot compete with the blast-furnace while there is a shortage of electric power which is used for more essential tasks than iron and steelmaking. Most recent reports of energy experts rule out the possibility of any change in the short-term situation.

(ii) the reduction processes to the solid state in which the metallic product retains practically all the gangue from the ore; this main limitation is reduced by the possibility of enriching economically a wide range of ores. Certain processes have now attained a notable degree of technical perfection (Wiberg, Höganäs) but because of the cost of operations (electric power, etc.) they are limited to producing high-quality materials for specialized uses.

The Krupp Renn process is very highly developed technologically, but is hampered by high fuel consumption, in requiring a strictly defined type of ore and in the relatively low quality product.

The fluidized bed processes seem very promising but from the operational results available up to the present there seem to be three difficulties requiring further research and development: the low rate of production, pyrophoria of the material, and the need to keep the particle size of the burden within well defined limits.

At the present stage of knowledge we think that apart from the possibilities which a sharp fall in the cost of electric power would open up, the direct reduction processes with a solid end product offer the best prospect of success and there is therefore a big incentive for research in this direction. Conditions which research projects in this field must satisfy to overcome difficulties already partly known appear to be the following:

(i) they must not be dependent on the use of raw materials favoured by local conditions

(ii) they must use reducing gas free from nitrogen for the gasification of ordinary quality coals; it should be possible to add natural gas or coke-oven gas according to local availability. To meet these conditions the use of oxygen is assumed and oxygen at the lowest possible cost is required.

(iii) they must exploit the use of gases to the maximum; purification and recycling of the gas is therefore necessary

(iv) they must ensure the maximum surface contact between the gaseous and the solid stage to shorten the time of reduction

(v) they must attain the maximum performance in insulation and heat exchange to achieve good heat economy; the direct reduction processes being carried out at a low temperature seem well able to satisfy this condition.

These are essentially the concepts which have guided the authors in outlining a programme of fundamental research in the report on Finsider II which has been approved by the ECSC Committee of Technical Research and which is being developed at the Instituto Siderurgico Finsider in Genoa with the financial assistance of the High Authority.

APPENDIX

The physical chemistry of the reduction of iron ore

The reduction reactions to metallic iron from the state of maximum oxidization are as follows:

$$Fe_2O_3+3C=2Fe+3CO$$
$$Fe_2O_3+3H_2=2Fe+3H_2O_{vap}$$
$$Fe_2O_3+3CO=2Fe+3CO_2$$

At 25°C the heat of reaction of reactions for carbon are[15]

$$\Delta H_{25°}=+117{\cdot}3 \text{ kcal/mol } (+1050{\cdot}1 \text{ kcal/kgFe})$$

For hydrogen

$$\Delta H_{25°}=+23{\cdot}4 \text{ kcal/mol } (+209{\cdot}5 \text{ kcal/kgFe})$$

For carbon monoxide

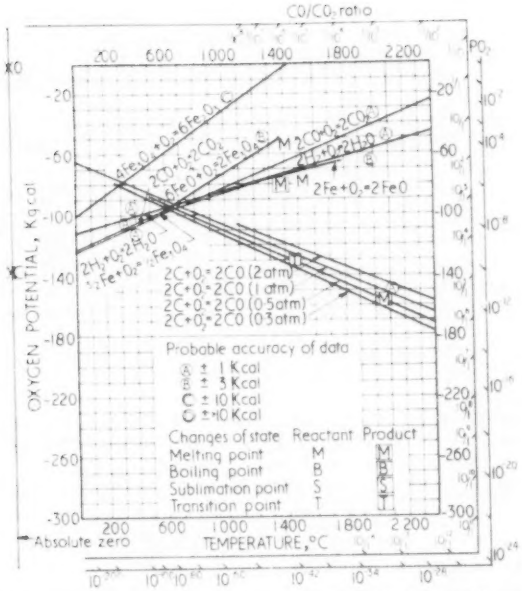
$$\Delta H_{25°}=-6{\cdot}3 \text{ kcal/mol } (-56{\cdot}4 \text{ kcal/kgFe})$$

The reactions are therefore endothermic in the case of carbon and hydrogen and exothermic in the case of carbonmonoxide.

In practice the reduction reactions occur gradually and Table VIII gives the values of Gibbs free energy relating to the various reduction reactions for all the iron oxides.[16] Table VIII gives the temperatures from which G is negative and shows the probability of the various reactions.

It should be noted that the reduction reactions with carbon are strongly endothermic and take place at high temperatures by which normally the metal produced is in the molten state. Therefore a process having a liquid end product in comparison with one with a solid end product has a fuel consumption at least 44 Mcal/ton higher owing to the melting point of iron. Taking into account the fact that the operating temperature is normally 500°C higher the additional energy consumption rises to about 170 Mcal/ton alone for heating the metal.

If further hot processing of the sponge iron was not necessary to transform it into usable metal this difference would put at a disadvantage the processes producing a liquid product. In practice, however, the positions can even be reversed in the sense that a sponge produced at 1000°C often requires cooling



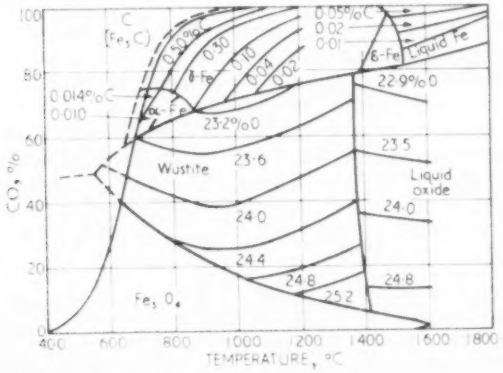
6 *Change of oxygen potential and pressure during transformation in oxide of 1 mole* O_2

before being reheated again to 1600°C in the steelworks and thus the first part of the heating energy, although less than that of a process with liquid product, is completely wasted.

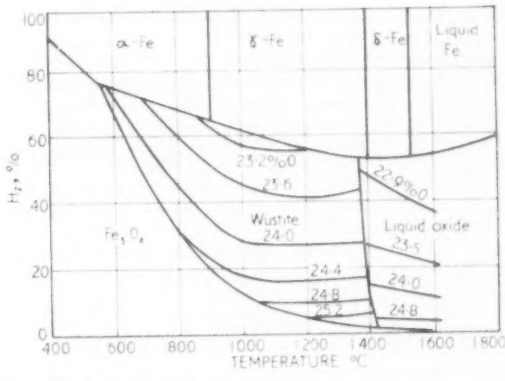
The reduction of the iron oxide proceeds by degrees as a function of the oxygen pressure of the intermediate iron oxides and therefore as a function of the ratio CO/CO_2 and H_2/H_2O of the gaseous phase.

The theoretical equilibrium ratios CO/CO_2 (*see* Fig.6 for the various partial reactions as a function of the temperature). In this graph[17] is shown the oxygen pressure of the main reduction reactions of the ferrous oxides. As reference condition the pressure of 1 atm has been taken for the gases, the solids and liquids are pure phases; this enables the theoretical equilibrium pressure of the oxygen for each reaction and for each temperature and the corresponding CO/CO_2 ratios to be read directly.

To read off the theoretical oxygen pressure it is sufficient to join the point *O* by the point on the line corresponding to the temperature taken and read off the PO_2 on the scale on the right of the diagram. The ratios CO/CO_2 can be read out in a similar way bearing in mind that the pole to be used in this case is the point *C*. Pooling the figures obtained for the various temperatures a diagram is obtained which shows the composition of the gaseous phase in equilibrium with various solid phases.



7 *Complete* Fe–C–O *diagram*



8 *Complete* Fe–H–O *diagram*

The complete diagrams relating to the equilibria Fe–C–O and Fe–H–O are given in Figs.7 and 8.[18] Equilibrium curves for the systems Fe–C–O and Fe–H–O are given in Fig.9. These reveal the existence of a triple point at about 570°C both in the case of the system Fe–C–O and of the system Fe–H–O; this point gives the decomposition temperature of the wüstite.

It should be noted that the homologous curves of reduction for CO and for H_2 intersect at about 810°C; above this temperature H_2 is a better reducer in the sense that a smaller equilibrium concentration is required; below this temperature CO is the better reducer. The curves shown represent equilibrium conditions (they do not therefore give any information about the kinetics of the reactions) and relating reactions which occur without variations in volume are therefore independent of the pressure. They relate to well defined iron oxides and do not therefore take account of the influence of other constituents which may be present.

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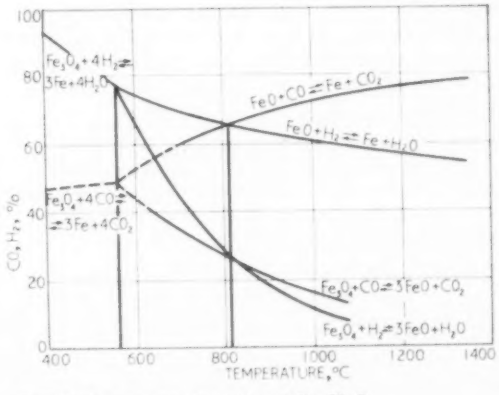

9 *Equilibrium curves* Fe–C–O *and* Fe–H–O

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Steels for forging

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DESCRIPTION OF PROCESSES

Drop (or hammer) forgings These shapes are produced normally in the hot state, by the application of an intermittent force. The shapes range from roughly moulded masses, as used for low-output components where the cost of intricate dies would not be justified, to close-limit forgings produced in closed dies.

Press forgings These are shapes produced, normally in the hot state, by a squeezing action, ranging from rough but extremely massive shapes as used in the heavy industries to close-limit forgings used for the quantity production of machined engineering components produced in closed dies.

Upset forgings These are shapes produced hot or cold in either horizontal or vertical forging machines, by application of force in a direction axial to the work-

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SYNOPSIS

For the purpose of this paper, forging is defined as 'the process of shaping in closed dies, by upsetting, or by extrusion, or by a combination of such methods, of either hot or cold metal'. The nature of the work put upon the workpiece may cause it to flow in any direction, the limits of flow being, in general, the boundary walls of the dies.

Consideration is given to the mode of work put on the steel in the forging or extrusion operation, and to those requirements regarded as essential for the ready working of the steel without the production of defective products from the dies; additionally, the requirements of the user of the shapes produced are considered in regard to the machinability of the steel and its quality in relation to any heat-treatment that may be necessary.

Processes covered by the scope of this paper are drop forging, press forging, upsetting, extrusion, and cold flow forging. 1783

piece, causing the metal to flow radially outwards. The process is applied to both hot and cold metal, an example of the latter being the production of cold-headed bolts.

Extrusions These are shapes produced by forcing the metal to flow through a die opening, or produced by displacement of the metal by forward or backward flow into a die cavity. The operation may be conducted either hot or cold, the hot process being normally used for the production of long lengths of section from large billets, whereas cold extrusion is, in the case of steel, normally applied to the production of individual components from small blanks or workpieces.

Cold flow forgings These are shapes produced in the cold state by applying an extremely heavy load to the metal contained between the dies, causing it to be displaced in order to fill the die cavity; the flow imposed may include upsetting as in the upset bolt industry, in which the outward flow may not be limited by the die walls, and also backward and forward flow through an orifice lying on the axis of the die stroke.

Of these processes, the most versatile are the conventional hot-forging procedures, which permit the production of all manner of shapes without any great difficulty, but unfortunately extremely close dimensional limits cannot be maintained and appreciable machining is necessary for the production of the finished components. Cold flow forging and extrusion, however, are capable of producing shapes to extremely close limits and to final form, so that material is conserved and labour costs reduced; in some instances, cold flow forging or cold extrusion is capable of producing in the finished components adequate mechanical properties for service requirements by virtue of the cold work that has taken place, using carbon or low-alloy steels, so that the hardening and tempering operations often necessary with conventional methods of production may be dispensed with.

STEEL QUALITY

It would be safe to assume that, for the various methods of shaping under consideration, the quality requirements are very similar, although their relative order of importance may vary; a list of the requirements is as follows:

(i) excellence of surface
(ii) freedom from segregation
(iii) uniformity of grain size
(iv) freedom from internal flaws
(v) minimum non-metallic inclusions
(vi) conformity with composition requirements
(vii) freedom from gross decarburization
(viii) machinability.

At the present time, several of these requirements are vaguely covered in the preamble to B.S.970, and to the employment of the designation 'forging quality', for which a premium is charged; however, before discussing this aspect of the problem, some attention will be given to composition requirements. All too often there is misunderstanding between purchaser and steelmaker because neither appreciates the other's problems, and it is more than possible that at times close-limit steels are specified when such a requirement is not strictly necessary; however, that is no excuse for the variation that so often occurs between consignments of steel. In the past, close-limit carbon steels have been demanded to achieve strictly controlled heat-treatment, but in the future it is more than likely that similar control will be necessary for the steels used for the production of extruded shapes and for cold flow forgings, particularly if the properties of steel for the latter process are to be under sufficient control to prevent undue wear and tear of the dies.

CARBON CONTENT AND HARDENABILITY

Special requirements of the customer that involve payment of a premium are close-limit ranges and specific hardenability; these are not unreasonable requirements with steel used for quantity production involving high-speed machining and precision heat-treatment. It is unlikely that both requirements will be specified for any one purpose, but close carbon limits are especially necessary for the manufacturer of components in both carbon and alloy steel of medium carbon content which have to be locally hardened or surface-hardened by either flame or h.f. induction methods. The term 'close-limit' is normally applied by the user to a carbon tolerance of $\pm 0{\cdot}025\%$, compared with the usual tolerance of $\pm 0{\cdot}05\%$. If consideration is given to the fact that B.S.970 states 'The specified ranges of chemical composition are based on cast analyses' and 'Any subsequent checks shall take into consideration the heterogeneity of the steel', it is pertinent to enquire exactly what these phrases mean. It is only when the user is supplied with steel that is outside the specified limits that he is informed that in addition to the specified carbon tolerance, be it either the normal or close-limit tolerance, he must also submit to its widening by another $+0{\cdot}03-0{\cdot}02\%$ for a medium-carbon steel, making the normal permissible range $0{\cdot}15\%$ or the close-limit range $0{\cdot}10\%$. It is only fair to add it is not often necessary for the steelmaker to claim the right to exercise this escape clause in B.S.970, but when he does it generally causes very considerable misgivings on the part of the user, and he then gets very interested in the possibility of specifying by type and by hardenability bands, rather than by strict composition limits.

A comparison of British and US specification practice on carbon limits shows very close agreement, taking medium-carbon steels as an example, but the AISI do at least publish the added tolerances the steel user can expect to occur. The tolerances for carbon over the specified range given in the AISI Steel Products Manuals are:

Carbon steel for forging		*Alloy steel for forging*	
Carbon up to $0{\cdot}025\%$	$\pm 0{\cdot}02\%$	Carbon up to $0{\cdot}30\%$	$\pm 0{\cdot}01\%$
Between $0{\cdot}25\%$ and $0{\cdot}55\%$	$\pm 0{\cdot}03\%$	Between $0{\cdot}30\%$ and $0{\cdot}75\%$	$\pm 0{\cdot}02\%$
Over $0{\cdot}55\%$	$\pm 0{\cdot}04\%$	Over $0{\cdot}75\%$	$\pm 0{\cdot}03\%$

It is a fact that close-limit steels are more readily available and more widely used in the USA, presumably owing to the greater speed with which heat-treatment has been accepted in that country as being capable of precise control on a quantity production basis; close carbon limits are also a more vital requirement with the more economic and lower alloy steels developed in the USA than in the case of the richer alloy steels which have been the custom in the UK in the past and

which have far greater tolerance for variations in quenching temperature and cooling speed.

Specification by hardenability has not achieved any degree of popularity over here, probably because in its most popular form (the Jominy test) it was first adopted in the USA as a ready means of assessing the possibilities of a variety of steels for given components. Simple hardenability (or quenching) tests are used by a number of steel purchasers as a means of control of incoming steels, but most metallurgists responsible for the bulk heat-treatment of engineering components would welcome the opportunity of giving greater latitude on chemical composition provided that there was adequate control of hardenability (or heat-treatment response). It is generally claimed by steel manufacturers that the US hardenability bands are very much wider than those applied to steels conforming to the requirements of B.S.970 for composition, but it would be interesting to have evidence of this fact for (*a*) British and US steels in strict conformity with close composition limits, (*b*) those steels with the close limits expanded by the heterogeneity clause, and (*c*) British steels with normal limits, expanded by the heterogeneity clause.

RESIDUAL ELEMENTS

Residual elements often cause the user some difficulties, both during machining operations and in heat-treatment; B.S.970 states that 'For carbon steel, elements not quoted in the specification shall not be intentionally added' and 'reasonable precautions shall be taken to prevent the addition of such elements from scrap, etc.' AISI documents are equally vague, but the user would prefer to know what limits of alloying elements he can be expected to tolerate, particularly as such limits are set for incidentals for alloy steels both in the US and the UK as follows:

	B.S.970	*AISI*
Ni	0·40%	0·25%
Cr	0·30%	0·20%
Mo	0·15%	0·06%
V	0·05%	...
Cu	...	0·35%

It will be noticed that the AISI tolerances are much lower than those of B.S.970, a position viewed with envy by the British steel user. It is worth observing that more difficulty is experienced in obtaining satisfactory forging-quality carbon steel than alloy steel, this comment applying to surface quality as well as to the inherent properties of the steel as represented by chemical composition and grain size; this is evidence that the extra care exercised in the production of alloy steel so necessary to prevent excessive scrap might well be applied to the manufacture of carbon steel. Cases have been known of carbon steel produced by steelmakers normally in the alloy trade that is quite up to the standard of their usual product but rarely vice versa.

It is an interesting fact that although our national standards, as represented by the publications of the BSI, permit many undesirable deviations from the detailed requirements, it is always possible to come to special arrangements with the steelmaker for close limits. Such a practice is not entirely desirable and generally carries with it a premium on the price charged; it should not be beyond the capacity of the steelmaker to achieve a regularly close control upon the composition and characteristics of those steels he produces for the precision engineering industries.

FORGING QUALITY

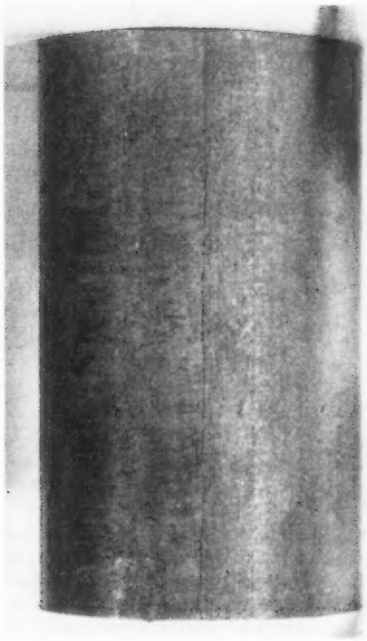
A comparison of UK and US practice in the realm of quality requirements may not be out of place, particularly as such requirements tend to be hidden away in the text of the appropriate standards publications; there has, undoubtedly, been a considerable misunderstanding of the true position, at least in the UK in the past.

The term 'forging quality' implies much the same requirements both in the UK and in the USA; the phrasing of the requirements in the relevant documents is as follows:

> *B.S.970:1955* Billets and bars for forging shall be rough-machined, chipped, ground, or otherwise prepared to remove defects which might produce defects in the bars, forgings, or drop forgings, to be made therefrom.
>
> *AISI Steel products manual. Semi-finished carbon steel products for forging—section 2* Semi-finished steel is commonly conditioned as necessary, by scarfing, shaping, or other means . . . Special surface can be specified.

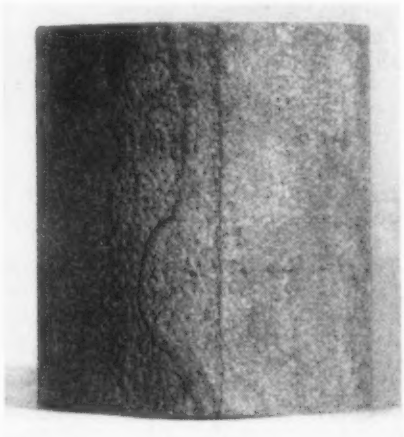
In both cases extra work is involved in the finishing of the steel and this obviously commands an extra charge; however, this fact is only apparent when the price schedule is examined. A plea is made here for improvements in technique to produce steel having an adequate surface for forging without recourse to expensive surface finishing operations. The user at present has the unavoidably wrong impression that progress made within the steel industry in this particular field of endeavour is not comparable with that made within the sphere of production engineering. It should be possible to maintain a satisfactory condition of the ingot mould surface by constant inspection and the employment of die dressings, followed by adequate care in teeming and in breaking down the ingot, so that the bloom or billet as supplied for forging is free from many of the undesirable surface defects which are so common at the present time and which necessitate such expensive conditioning procedures. The customer is left with the impression that he has to pay for the lack of good housekeeping by the steelmaker, whereas he himself is being continually forced by competition to reduce his manufacturing costs by improved techniques.

An examination of the price structure covered by the Iron and Steel Board shows that extra charges are involved in the purchase of a fully reliable steel for (*a*) forging (or up-ending) quality, (*b*) grain-size requirements, (*c*) inclusion count requirements. There are, of course, numerous other extras for special composition or mechanical property limits or ranges which might be regarded as just and reasonable, as are the extras for specific melting procedures, but the requirements shown as extras are those which might conceivably be considered to fall within the manufacturer's normal pride in his product. The fact that steels can be produced to meet the foregoing specific quality requirements implies either that the steel is specially made, or that it is specially selected. In either case it provides evidence that the user's requirements, which are in general justified, can be met, and that the

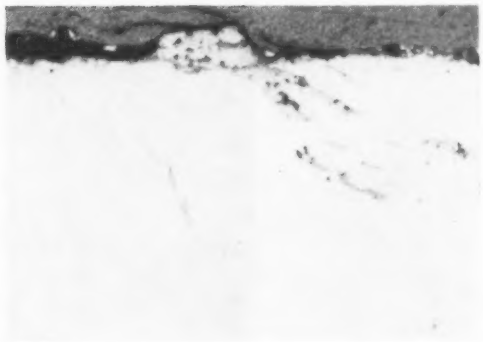


1 *Seam*

quality of the steel as produced can vary either intentionally or unintentionally. The purchaser is left with the feeling that he is being held to ransom for a quality requirement which may at one time quite rightly have been a special requirement, but which by now should be a normal undertaking, and he therefore seeks evidence from the steelmaker to justify the not inconsiderable premiums that have to be met. What the purchaser is in fact having to do is to pay for a guarantee that the steel will fulfil those functions required of it, i.e. forge satisfactorily without surface bursts resulting from surface imperfections, or internal faults resulting from segregation, and that it will provide a product that will not only machine satisfactorily without undue wear of the tools, but also respond uniformly to standard heat-treatment practice.



2 *Seam, lap, and poor general surface*



3 *Rolled-in scale* ×100

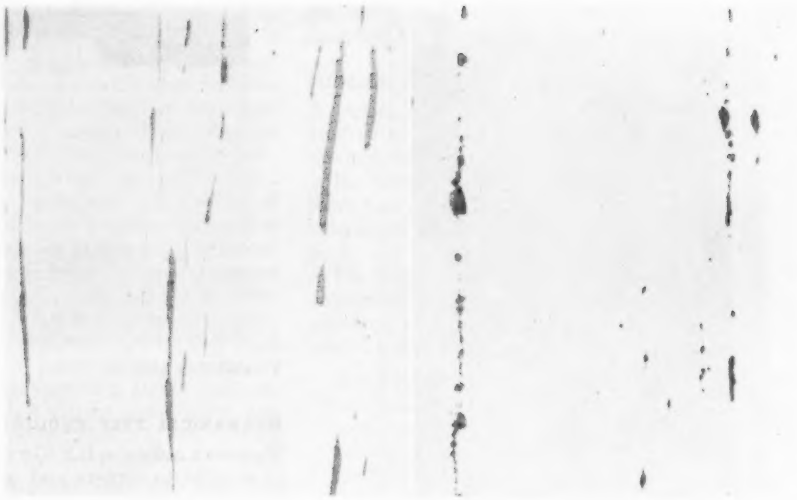
MECHANICAL TEST REQUIREMENTS

There is a clause in B.S.970 which has caused occasional trouble to forgers and users, and which is worth some discussion; this is clause 7b, covering the heat-treatment for testing of steel having an ultimate tensile strength of at least 85 tons/in^2. This requires testing to be carried out on a test-piece heat-treated in the finished test piece size, rather than on a test-piece machined from a heat-treated section of the appropriate size. An escape clause is included to the effect that the properties obtained 'may not represent larger ruling sections'. While it is acknowledged that machining of test-pieces at such high tensile levels is not easy, some better way of assessing the properties of the heat-treated steel appears to be necessary, particularly when such steels are included for applications involving ruling sections up to 4 in.

COLD EXTRUSION, IMPACT EXTRUSION, AND COLD FLOW FORGING

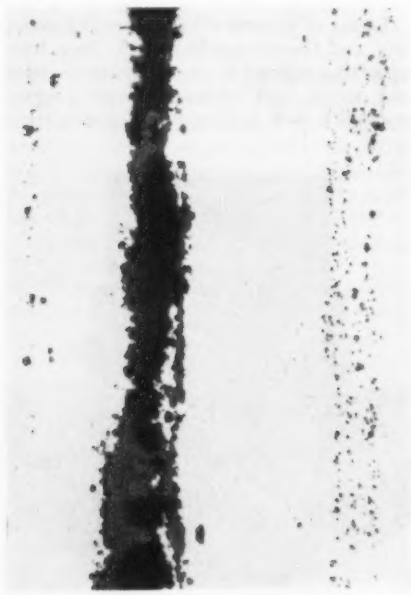
These terms are used to cover the designations generally applied to the cold forming of components, normally of symmetrical form. In comparison with hot forging, the art of these methods of cold forming is in its infancy, and the science has barely been born. The simple upsetting of steel in the cold state is, of course, of ancient origin, and while in recent years it was widely applied to low- and medium-carbon steels, it is

4 *Surface splits due to seams*



5 *Non-metallic inclusions* ×100

now regularly used for the lower-alloy steels. The best example of cold upsetting in the engineering industry is the manufacture of cold-forged bolts; the steel requirements are those enumerated earlier, excepting that the structural condition of the steel as worked is of considerable importance. The initial structural condition of steel for hot-working is of no great consequence, provided that the inherent grain size is within desirable limits, as shaping is carried out at a temperature when the steel is not only plastic but also has a single-phase structure, being within the austenitic range. When cold-worked, however, the steel possesses an agglomerate structure of ferrite and carbide having a varying degree in the dispersion of the carbides, and in the form of the grains, so that the mechanical properties of the steel at the time of working are capable of varying quite widely. The effect of these variations would appear at first to be serious, but there is some evidence that the speed of working is so great that they have less influence than might be anticipated, and it is hoped that this effect of speed on the properties of steel will be discussed elsewhere.

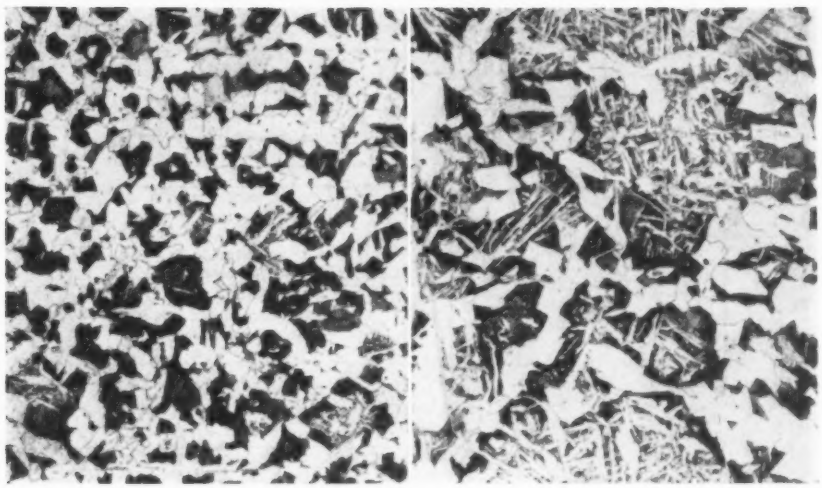


6 *Pipe in billet* ×100

The need for freedom from surface and internal defects is not limited to steels required for either hot or cold forming, hence the need in many instances of the light engineering industries for steels required for high-speed machining to have a precise inclusion count and in some instances a machined surface. The inclusion count requirements are required principally for consistency in machining characteristics, while the machined surface is necessary to eliminate surface defects such as seams and surface lines and also the decarburized surface layers, freedom from decarburization being especially necessary in steel required for flame- or induction-hardened components. Care in steelmaking and in the hot-working stages should eliminate, or at least considerably reduce, both the extent and the incidence of these defective conditions. It would appear that the fact that some industries tolerate, if not encourage, some decarburization as an aid to their particular forming operations is no excuse for the belief that, if the customer requires freedom from these defects he must pay to have them removed. Control of the atmosphere of reheating furnaces might be a step in the right direction in the elimination or reduction of decarburization, and recarburization by atmosphere control is not an impossible procedure, as proved by its adoption in the US.

DEFECTIVE CONDITIONS IN STEEL AFFECTING THE PRODUCT

Typical examples of the surface condition of hot-rolled billets and bars, purchased as 'forging quality', but without the imposition of any other special surface requirements are shown in Figs.1–3, together with the type of defect to which they give rise in the finished forging (Fig.4). These examples occurred in the course of normal supplies of material and were not specially selected for the purpose of illustration. It appears that under present steel-manufacturing conditions, where a good surface is necessary, machining of the ingot, of



a b

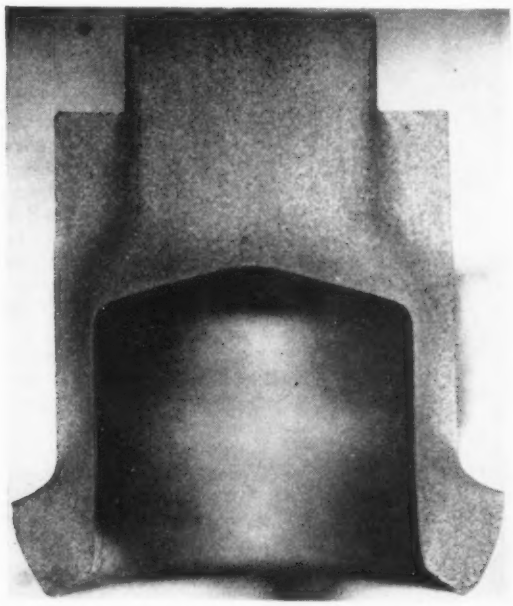
7 *SAE 8615 (En 351) billet:* (a) *surface,* (b) *centre* ×100

the billet, or preferably of the bar, is necessary, certainly when the material is required for making either close-limit forgings or cold flow forgings, but such a requirement imposes an unnecessarily high additional cost particularly if the surface preparation is carried out by the steelmaker.

Non-metallic inclusions are not only detrimental in machining, but are also likely to cause 'bursts' in the surface of forgings, both of the conventional and of the cold flow type, particularly if an upsetting stage is included in the forming operations, should the inclusions occur in the surface layers. Examples, again not specially selected, are shown in Fig.5 of hot-rolled bar or billet material purchased for the manufacture of cold flow forgings, and a further example is provided in Fig.6 of gross piping in one end of a random bar, evidence of insufficient discard in manufacture.

Although it has not yet been established which is the best structure for cold extrusion or cold flow forging, the customer can surely expect a reasonable degree of uniformity in hot-rolled billets and bars with reasonably sized grains; an example of the variation in structure which may be encountered, and which has not been specially selected, is shown in Figs.7*a* and *b*.

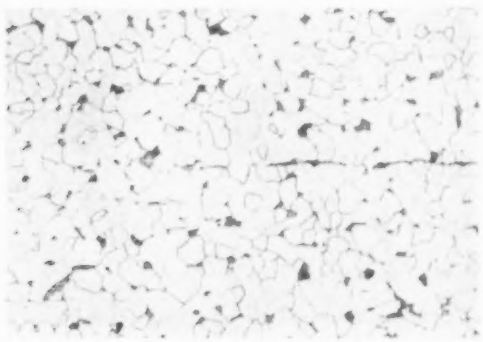
All these examples have been taken from recent supplies of material purchased for the manufacture of conventional hot forgings, but which were used in experimental cold-flow forging investigations; in each case the orders carried the endorsement 'forging quality'. Is the purchaser to accept these examples as being the best standard available, without incurring further added charges, and in any case is it possible to have a definite statement as to the meaning of the term 'forging quality'?



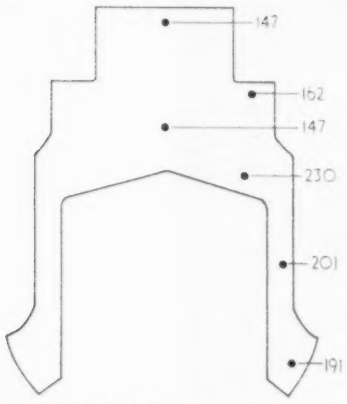
8 *Etched section of cold-extruded wheel nut* ×3

ADVANTAGES OF COLD FLOW FORGING AND STEEL REQUIREMENTS

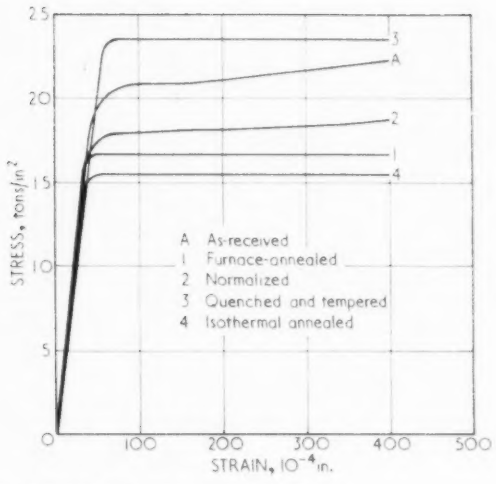
The improvement in the mechanical properties of metal by cold work has been taken advantage of since the days of antiquity. In the present age the effects of cold work are taken for granted even though they are, as yet, incompletely understood. We are all familiar



9 *Photomicrograph of En 2A steel used for wheel nut* ×100

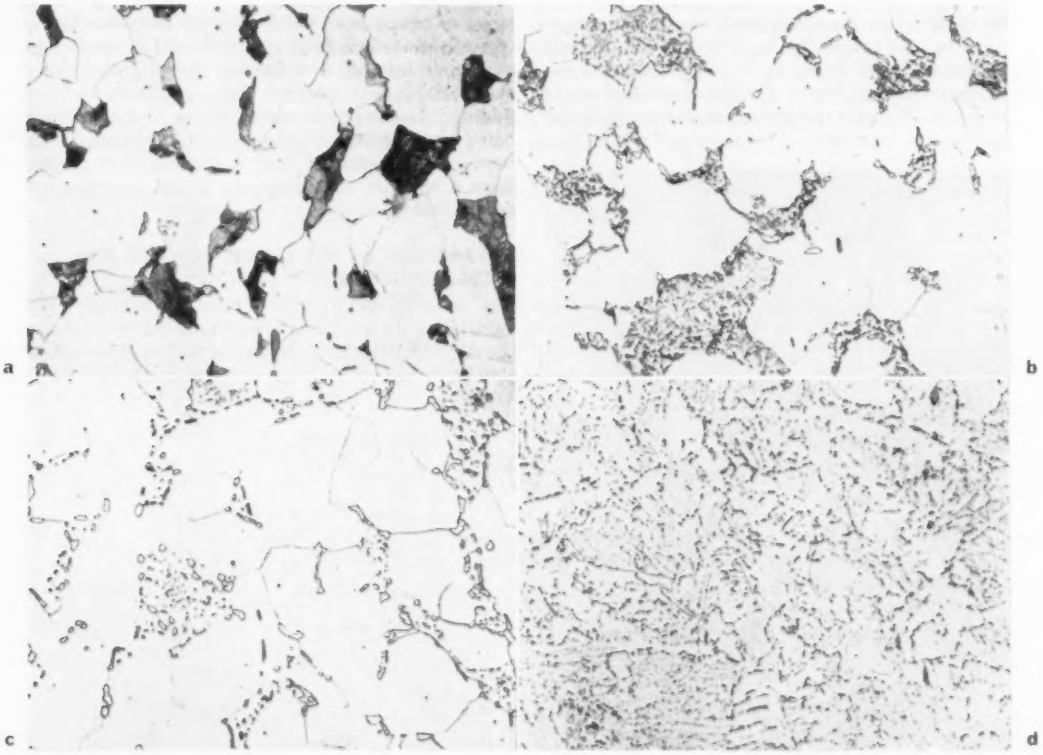


10 *Hardness survey of wheel nut*

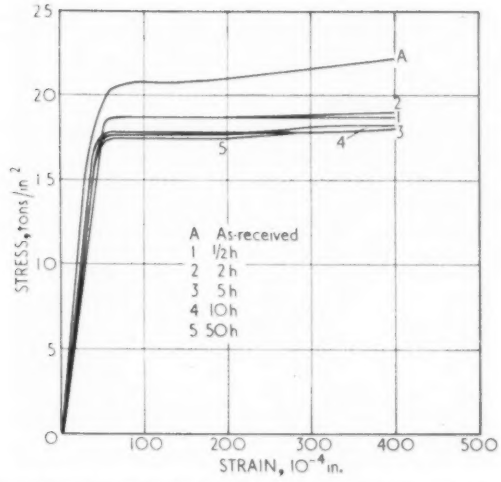


12 *Effect of different treatments on En 3B*

with the effect of cold work on the ultimate tensile strength and the associated reduction of proof stress, with restoration of the latter by low-temperature treatment. At present, however, we are interested, among other things, in the possible effect of cold forming by extrusion, or by a combination of extrusion and upsetting as a means of achieving economies not only in material and in labour costs, but also in heat-treatment costs. The possibilities of economies in material and labour can be judged from Fig.8, which is the section of a simple cold-extruded component. The metallurgist is also interested, however, in the possibilities of reducing processing costs by the elimination of the hardening and tempering operation, yet at the same time achieving the requisite strength with, in some cases, much lower alloy steel or even a carbon steel for applications in which high-alloy steels have previously been used. The wheel nut illustrated was produced from a mild-steel slug (Fig.9) having a hardness of 120 DPN, the hardness pattern



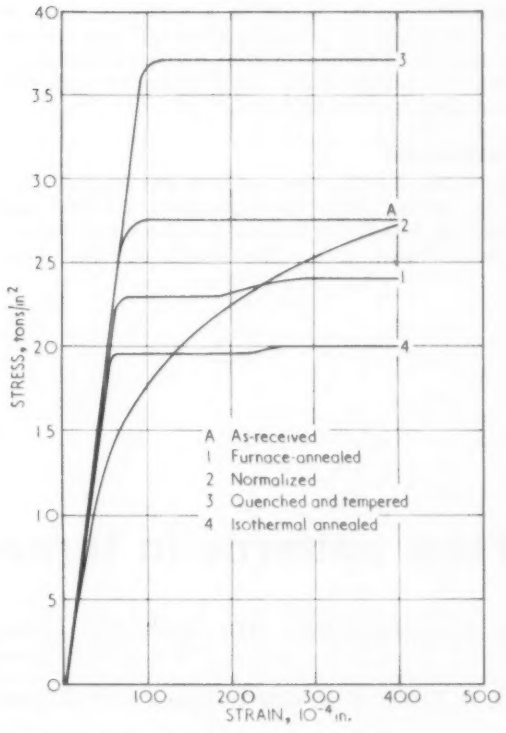
11 *Steel En 3B: (a) normalized, (b) after sub-critical anneal for 5 h, (c) after sub-critical anneal for 50 h, (d) quenched and tempered* ×500



13 *Effect of time on En 3B sub-critically annealed at 700°C*

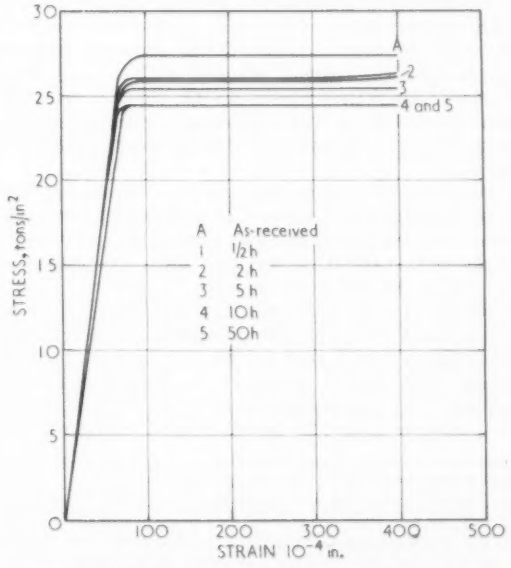
in the component being as shown in Fig.10. To take advantage of the cold work, any heat-treatment that may be considered necessary for extruded or cold flow forged shapes to eliminate strain-age embrittlement would have to be at a sub-critical temperature (e.g. 450–500°C), in order to maintain the high resultant strength of the cold-worked steel. It is obvious, however, that the advantages of the induced strength are limited to components that are to replace those which are normally through-hardened; those having wear-resistant requirements will still have to be surface-hardened by one of the conventional heat-treatment processes.

The degree of work possible in the various forming stages and the properties of the finished component will, to a large extent, be dependent upon the initial properties of the steel. Some years ago it was stated,* 'At present insufficient information is available on the influence of different heat-treatments, particularly with regard to the properties of the finished product', and this summarizes the present position. When consideration is given to variations in structure, illustrated in Figs.11*a–d*, which would be reflected in the physical properties of the steel, the apparent combinations of structure with tool design and press variations are almost limitless. However, reference to Figs.12 and 13 shows that for mild steel a sub-critical anneal at 700°C for as short a period as ½ h produces a difference of only 1½ tons/in² in the yield point, as compared with the same treatment for 50 h, and should, therefore, result in little effective difference in the force required for cold forming, even though the degree of divorce of the carbides and their spheroidization is completed by the latter lengthy procedure. Although quenching and tempering produces a uniform structure, the only way in which the yield point could be reduced after quenching would be by lengthy sub-critical annealing and there would be no benefit over direct sub-critical treatment without quenching. Isothermal annealing should, theoretically, produce the most satisfactory condition in the steel, but such treatment is somewhat more expensive and requires



14 *Effects of different treatments on SAE 8615*

specialized heat-treatment equipment. Similar curves are obtained with an alloy case-hardening steel, as shown by Figs.14 and 15, except that the difference in yield point with an extreme variation in the sub-critical treatment time is slightly greater. From the stress/strain diagrams shown, it would appear that the best pre-treatment for steel used for cold extrusion and



15 *Effect of time on SAE 8615 sub-critically annealed at 700°C*

* D. V. Wilson: *Proc. SASMUTA*, 1951–2, **5**.

cold flow forging would be a relatively short sub-critical anneal, a normalizing conventional annealing in the case of low-carbon steel, and isothermal annealing, furnace annealing, and prolonged sub-critical annealing for low-alloy steel.

CONCLUSIONS

An endeavour has been made to provide evidence of some of the difficulties experienced by steel users, with the underlying reasons for what might appear to the steelmaker to be unnecessarily exacting requirements. If discussion of the vexed subject of steel quality is stimulated, the author will be well satisfied.

ACKNOWLEDGMENTS

Thanks are due to the directors of The British Motor Corporation for permission to present this paper, and to many of my colleagues for the provision of data and illustrations.

(*The discussion on this paper appears on pp. 315–324 of this issue.*)

Flow patterns in three-dimensional shapes

A BACKGROUND FOR FURNACE DESIGN

N. P. Bacon, J. H. Chesters, and I. M. D. Halliday

SYNOPSIS

Earlier work on two-dimensional flow patterns has been followed by studies on cubes, spheres, cones, cylinders, and other three-dimensional shapes. It is found that with solids of revolution or shapes produced by sideways translation the basic flow pattern can be predicted from the two-dimensional studies. New factors are, however, found, notably swirl. Enclosed jets behave initially like free jets but do not entrain along the whole of their length; the finite entrainment zone being followed by a null zone and a zone of discard, the latter providing the return flow for entrainment at the root of the jet. Flow in the cube may be considered as the general prototype for all furnaces, while that in the sphere and hemisphere, illustrates the kind of flow which occurs when, say, gas holders are filled and ignition hoods used on sinter strands. The cone gives the basic pattern in a burner quarl, while the cylinder indicates the peculiarly unstable conditions associated with the flow in Lancashire boilers, flame tunnels, and rotary kilns. 1805

SOME TEN YEARS AGO a series of flow-pattern studies intended to explain the movement of gases in the open-hearth furnace was published.[1] Part I of the series, entitled 'Flow patterns in ducts', gave the results for two-dimensional geometrical shapes and included references to such literature as was then available. This work was followed shortly afterwards by parallel studies on cubes, spheres, cones, cylinders, and other three-dimensional shapes; while in 1954 the work was repeated under more precise conditions and photographs were obtained of the principal patterns. Apart from the results obtained with a cube, which were discussed in a recent ASME paper,[2] this three-dimensional work has remained unpublished. The present paper makes this background information available.

Work has also been done on the dwell time of fluids in three-dimensional shapes, various containers having been filled with acid and the change in concentration at the exit measured when clean water was passed into the shape at particular points. No attempt will be made to present these results here but it is worth noting that with the shapes tested, i.e. a sphere, a hemisphere, a cube, and a series of cylinders of varying length, the period required to reduce the tracer material to a given fraction of its original concentration decreased with the proportion of recirculation. It is suggested that a similar method could be used for studying flow and recirculation in full-scale furnaces or water-cooling systems. All this work was carried out with the principal object of obtaining an aerodynamic background to combustion and heat transfer studies, but many of the results are equally applicable to other engineering problems, e.g. the mixing of fluids in large tanks,[3] or the design of dust extraction equipment.[4]

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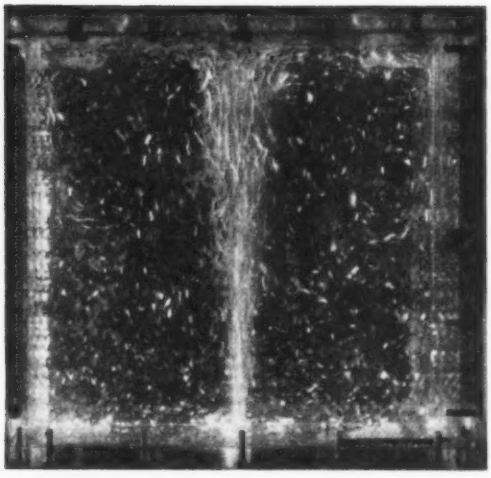
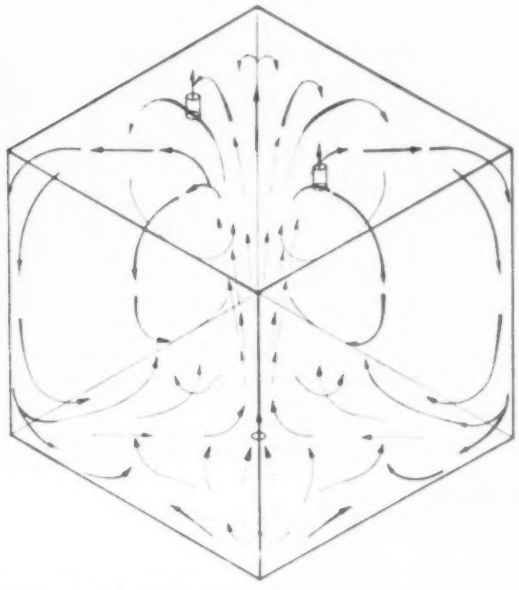


1 *Flow visualization in three dimensions. Plane of the jet in a cube with tracer fed into inlet stream*



2 *General flow pattern in cube*

Study of textbooks on hydraulics shows that much relevant work has been done on this whole problem of three-dimensional flow, e.g. the classic studies of Osborn Reynolds,[5] on the conditions determining transition from laminar to turbulent flow, and Karman's work on micro- as distinct from macro-turbulence, discussed for example in Prandtl's book[6] in connexion with the problem of flow in pipes. Very little appears to have been published, however, on flow patterns in even the simpler geometrical shapes, although these are an essential feature of everyday life. The general explanation would appear to be that the hydraulic and aerodynamic experts have been too busy studying flow *around* such shapes as ships, aeroplanes, and cars, to be particularly interested in flow *through* or *within* such shapes as furnaces, tanks, bends, and valves. Much work has been done on free jets[7] but until recently comparatively little on jets in enclosed or partially enclosed envelopes. Most of the three-dimensional flow patterns available still refer to special shapes, e.g. the open-hearth furnace,[1, 8] and jet engine flame tubes.[9]

EXPERIMENTAL PROCEDURE

The general procedure adopted in making perspex models was described in earlier papers,[1] though numerous detailed improvements have been made, for example in the tracers used and the type and intensity of light sheet. In the present work a supply of water was fed to the model from a 300-gallon tank by a pump driven by a 10 hp motor. Flow visualization was achieved by using aluminium powder, as in the earlier work, or polystyrene powder (22–44 BSI mesh). This latter is colourless and has a specific gravity very close to that of water. Its only disadvantage is its relatively low reflectivity. A high concentration of tracer was held in a reservoir connected in parallel to the water supply line of the shape being examined. On opening the valve it was injected into the system and photographs taken of the flow pattern before appreciable deposition could occur. Exposures between 1/8 and 1/30 s were found to give suitable track lengths with the flow rates involved. These latter were usually about 80 cm^3/s, which, with vessels of the dimensions given below, corresponds to a Reynolds No. for the jet of 11000 and a mean jet velocity of 5·3 ft/s.

RESULTS

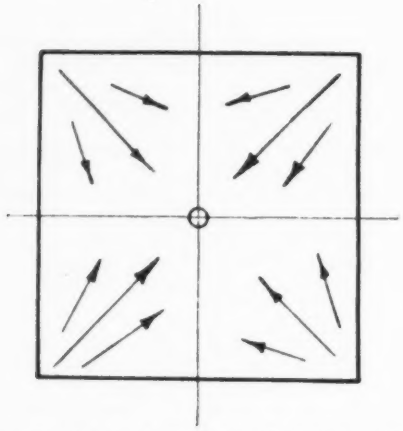
Although photographs (*see* Fig.1) were taken of most of the flow patterns discussed later the results are in general best expressed by simplified isometric drawings. Photographs possess the additional advantage of indicating velocity from the track lengths but it should be noted that such observations can be misleading owing to the precise direction of flow not being known. For convenience the flow patterns are described and shown in figures with the inlet jet directed vertically upwards. It should be noted, however, that in the absence of buoyancy effects the precise orientation of the shape is not important.

The cube

Relevant dimensions are:

model size 8 in. edge,
inlet one, $\frac{5}{16}$ in. dia. at face centre,
outlets two, at 4 in. centres, $\frac{5}{16}$ in. dia., located on centreline of the face towards which the inlet jet was directed.

The basic flow pattern (Fig.2) shows a central expanding conical jet, which on reaching the upper face of the cube spreads radially to the four side walls, return flow being initially downwards over all faces of the cube. The main return flow is, however, confined to the corners formed by the side faces. On hitting the bottom face of the cube these four streams spread radially (Fig.3) and meet on the arms of a cross, the centre of which is at the inlet jet and the arms of which are parallel to the edges of the base of the cube. The flow then turns upwards, much of the fluid being entrained into the inlet jet. The length of the entrainment zone would appear to be about two-thirds the cube length.



3 *Flow pattern in cube showing return flow at entry end*

The sphere

Relevant dimensions are:
model size 4 in. radius,
inlet one, $\frac{5}{16}$ in. dia.,
outlet one, $\frac{5}{16}$ in. dia.
Both inlet and outlet are on the same sphere axis.

Figure 4 shows the flow pattern to consist of a central expanding jet, which on reaching the top of the sphere is diverted outwards, the main return flow being downwards in the vicinity of the surface of the upper half of the sphere. This flow is mainly against the concave walls; it is stable in character and relatively free from swirl, i.e. the flow is direct from north to south along a great circle. On passing into the lower half of the sphere the return flow tends to become unstable and turns inwards to provide entrainment to the central jet and upwards to entrain into itself. Part of the main flow, however, continues downwards and is entrained into the jet near its base. The pattern in the lower half of the sphere shows considerable fluctuation and a marked tendency to rotate. Near the base of the jet there is a series of moving vortices in the surface flow which themselves rotate around the inlet jet.

The hemisphere

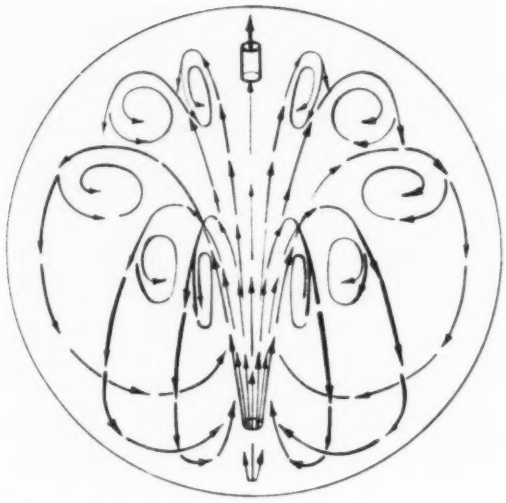
Relevant dimensions are:
model size 4 in. radius,
inlet one, $\frac{5}{16}$ in. dia.,
outlet one, $\frac{5}{16}$ in. dia.

Jet directed away from the flat side

The flow pattern with this arrangement (*see* Fig.5) is similar to that in the upper half of the sphere, the central jet spreading radially outwards on reaching the curved side of the hemisphere and then spreading downwards almost to the flat base before turning inwards and moving towards the central jet. There is no marked tendency for swirl and the flow pattern has the same general appearance in any vertical plane containing the jet axis. In this section the pattern is similar to that in the two-dimensional semi-circle, or rather the pattern that would result from the rotation of the two-dimensional version around its axis.

Jet directed towards the flat side

Figure 6 shows an isometric view of this pattern,



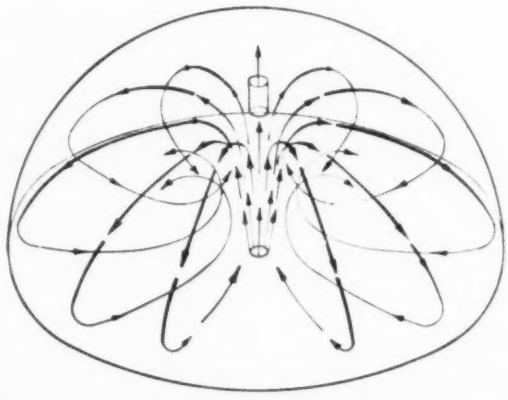
4 *General flow pattern in sphere*

which is also of a simple recirculatory type. After spreading under the flat face the flow pattern turns downwards, following the curve of the hemisphere for a short distance before rolling inwards and upwards. This results in a region near the surface of the hemisphere and close to the base of the jet in which the flow pattern continually fluctuates. The pattern in a vertical section is again similar to the two-dimensional case and shows return flow characteristics similar to those seen in the lower half of the sphere.

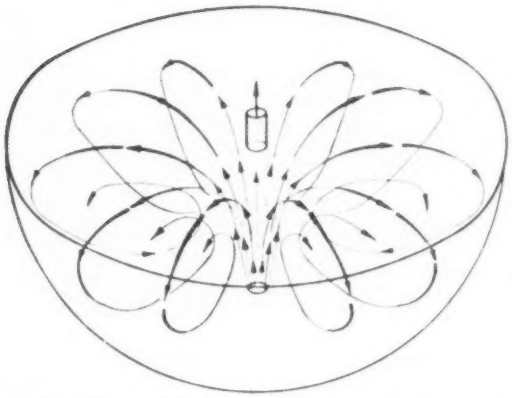
The cone

Relevant dimensions are:
model size base 9 in. dia.,
slant height 9 in.,
inlet one, $\frac{5}{16}$ in. dia. at the apex, pointed along the axis,
outlet two, $\frac{5}{16}$ in. dia. on centreline of base at $7\frac{1}{4}$-in. centres.

The flow pattern in this shape is markedly similar to that obtained by rotation of the pattern within the corresponding equilateral triangle. The jet spreads



5 *General flow pattern in hemisphere, jet directed away from flat face*



6 *General flow pattern in hemisphere, jet directed towards flat face*

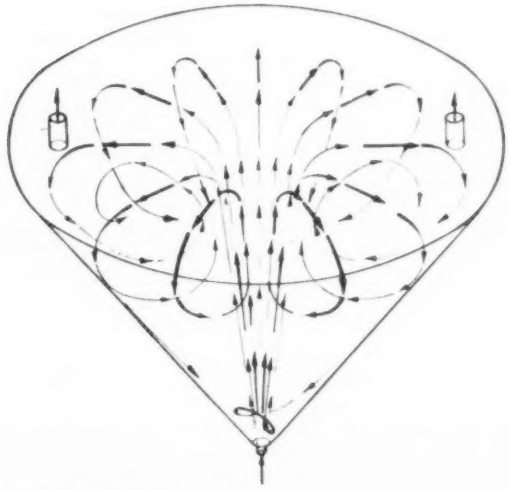
under the flat base of the cone (Fig.7), turns downwards and then rolls inwards, most of the flow being involved in a toroidal roll or vortex occupying the third of the cone depth nearest the base. The remainder of the flow is entrained along the length of the jet, a small proportion recirculates to the apex and before being entrained swirls around the axis.

The ellipsoid (revolution of ellipse about its major axis)

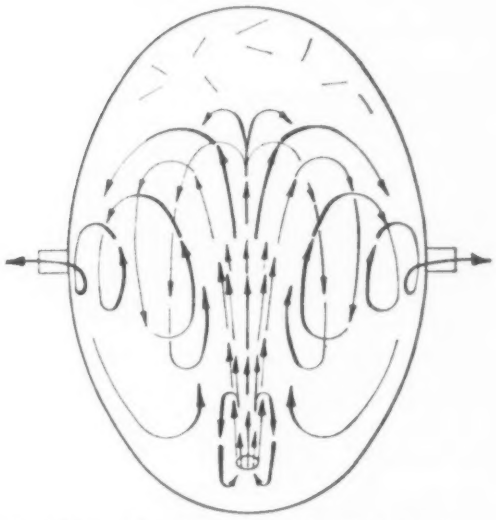
Relevant dimensions are:

model size major axis 8 in.,
minor axis $5\frac{1}{4}$ in.,
inlet one, $\frac{5}{16}$ in. dia., directed along the major axis,
outlet two, $\frac{5}{16}$ in. dia., in line along the minor axis.

Figure 8 shows the somewhat complex flow pattern with this particular shape. The jet travels along the axis of the ellipsoid, is diverted, and flows back towards the base. Superimposed on this relatively simple pattern is an asymmetrical component, possibly initiated by slight misalignment of the inlet jet. The incoming jet is bent over to the right shortly after entering, by a return flow sweeping down from one side, across the jet and over to the other side. The



7 *General flow pattern in cone*



8 *General flow pattern in ellipsoid with jet on long axis*

pattern fluctuates somewhat but is generally stable on a macro-scale possibly because of its asymmetry, instability being a marked characteristic of symmetrical arrangements in two-dimensional ellipses.

The cylinder

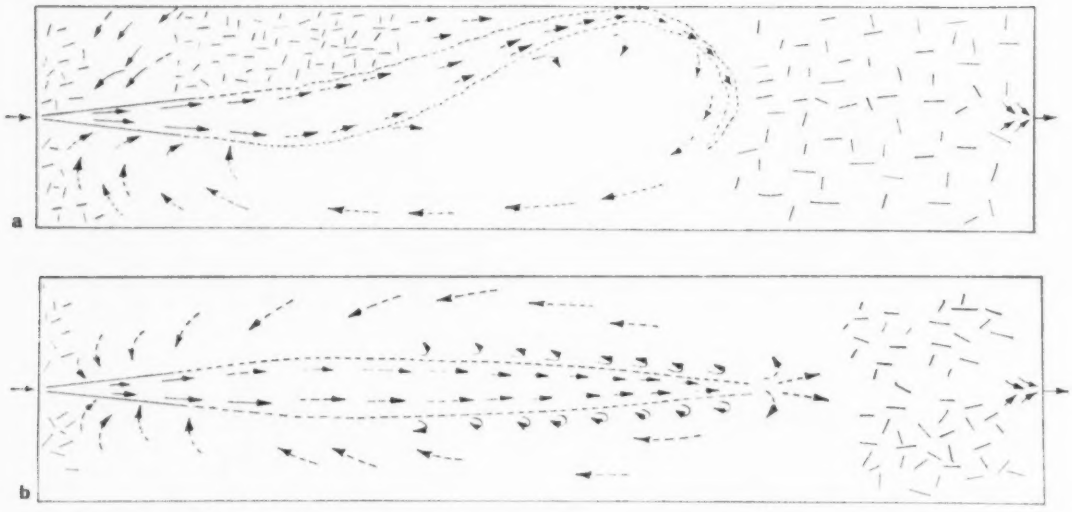
Relevant dimensions are:

model size length $17\frac{3}{8}$ in.,
dia., $3\frac{7}{8}$ in.

Studies have been made of flow in cylinders fitted with axial jets of the non-swirl and swirling types. Where non-swirling jets were employed with a nozzle diameter of $\frac{9}{64}$ in. and flows of 80 cm^3/s, marked instability was observed, the initial flow being similar to a free jet but the tail flapping violently and irregularly across a horizontal plane (*see* Fig.9). Such conditions might be expected, in that such a jet would normally expand until it sealed off the surrounding cylinder. Low pressure would then develop at the entry end, owing to entrainment, and return flow would take place at a point on the circumference where resistance was least. If the jet is turned slightly off axis, return flow immediately becomes strongest on that side of the cylinder furthest from the jet. When axial flow is attempted instability results, often observable as precessing of the jet stream. This result has also been observed on actual furnaces, difficulty being experienced in producing a stable flame along the axis even in a vertical cylindrical furnace. With swirling jets, which yield in free air, with a nozzle dia. of $\frac{1}{8}$ in., a cone angle of 70°, very different patterns were obtained (*see* Fig.10), entrainment occurring both on the inside and outside of the cone. With such jets shorter mixing lengths were obtained and a swirl pattern was set up that persisted throughout the entire length of the cylinder. Certain of these effects have been investigated more quantitatively for the case of a rectangular duct, by Curtet and co-workers.[10]

GENERAL CONCLUSIONS

Although the details of flow pattern in three-dimensional shapes can only be determined by direct



Nozzle dia.: $\frac{5}{16}$ in.; cylinder: $3\frac{1}{8}$ in. dia., $17\frac{3}{8}$ in. long; flow: 85 cm³/s.
Observations were taken with liquid flowing horizontally. Tail of jet flaps violently and irregularly across horizontal plane for which two patterns are shown

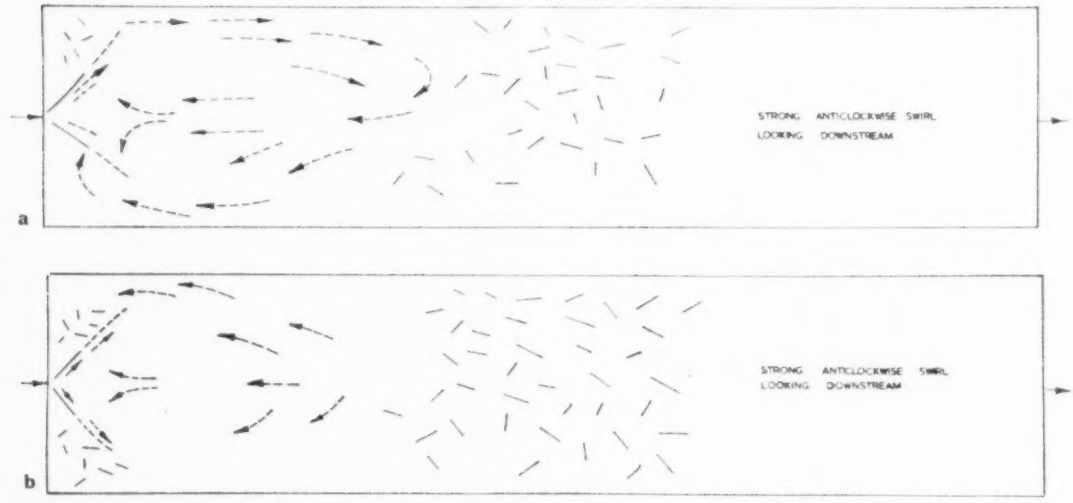
9 *General flow pattern in cylinder with non-swirling axial jet*

observation, certain generalizations can be made. These may not apply to conditions other than those described above but are nevertheless useful aids to thought. They can be summarized as follows:

1. The flow pattern in a three-dimensional geometrical shape can be partially predicted if this shape is a solid of revolution, or can be produced by sideways translation of the two-dimensional shape. Thus the flow in a cone when a jet is introduced through the apex is almost the same as that obtained by rotating the flow pattern for the triangular dish, while the flow in a triangular prism with fluid entering along one edge and perpendicular to the opposite face might be predicted from sideways translation of the triangular flow pattern. An example of this latter procedure is given by flow in a right-angle bend from an open-hearth furnace into the downtake. Provided the conditions close to the side-walls are ignored this is predictable from flow in the corresponding two-dimensional model.

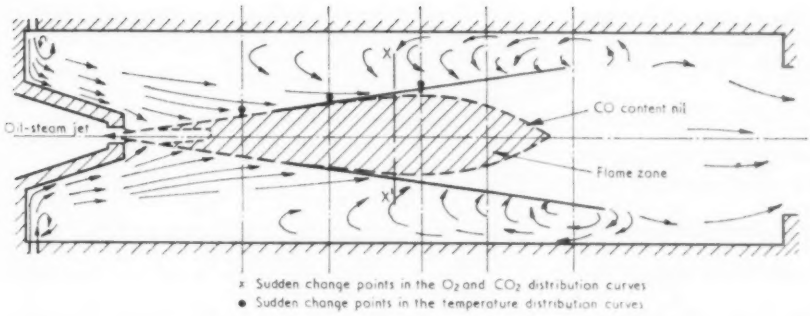
2. Three-dimensional shapes frequently show swirl that cannot occur in a two-dimensional section. This is, for example, found with the cone.

3. Enclosed jets tend to behave initially like free jets but differ from these in that they do not entrain along the whole of their length. The zone of entrain-



Nozzle dia.: $\frac{1}{8}$ in.; cylinder: $3\frac{1}{8}$ in. dia., $17\frac{3}{8}$ in. long; flow: 85 cm³/s. Cone angle of spray in free air: 70°.
Observations were taken with model mounted horizontally. Outline of jet disappears rapidly; patterns taken in horizontal plane.

10 *General flow pattern in cylinder with swirling axial jet*


Oil-steam jet
CO content nil
Flame zone
x Sudden change points in the O_2 and CO_2 distribution curves
• Sudden change points in the temperature distribution curves

11 *Flow pattern in IJmuiden flame tunnel (as reported by R. Durand and G. Cohen de Lara, Neypric, Grenoble)*

ment is finite, its size depending on the particular conditions existing in the model. Downstream it is followed by a null zone and a zone of discard, where stagnation and varying degrees of instability occur. The discard zone provides the return flow subsequently entrained by the earlier part of the jet. This is the condition for cases where the enclosed jet constitutes the only entry of fluid to the shape.

4. Where another secondary entry flow is supplied to the shape, for example the condition in the more complicated open-hearth furnace model,[11] or in the IJmuiden tunnel illustrated in Fig.11, the secondary flow may be arranged to supply part or all of the entrainment to the jet at the expense of, or in parallel with, some of the return flow. In such cases the return flow is a mixture of the two fluids entering the shape and the system is the essential basis of mixing and combustion in flame-fired equipment. As indicated in previous papers, the high-velocity jet still determines the main flow pattern, and being enclosed within a given shape, its limited entrainment zone is, for the most part, unchanged. However, the pattern of low-velocity flow in the surrounding regions may be affected by the secondary flow short-circuiting the basic single jet pattern described in these models.

APPLICATIONS

Comparisons with a cone were taken a stage further by building a hot model,[12] fired through the apex by means of a gas burner. This was found to show the essential characteristics observed in the three-dimensional water model. Although strict parallelism is rarely observed the patterns are basically similar, the main difference between models and furnaces being that in the geometrical models described all the fluid enters at one point, whereas in practice the normal procedure is for a high-velocity fuel jet to enter a relatively low-velocity air stream. If the difference in velocity or momentum is very great the pattern may be similar, but where the momenta are comparable further water-model work is necessary before flow pattern can be predicted.

The cube

This may be considered as the general furnace prototype. Extended endways it forms the simplest type of open-hearth or reheating furnace chamber, fired from one end and exhausted through the other. It also forms the approach to the flow pattern[2] observed in the flame tunnel at IJmuiden (*see* Fig.11), and explains the type of flow observed in the slag pocket of an open-hearth furnace, where the latter is entered from above through a relatively narrow centrally located downtake (*see* Fig.8 in a recent paper by Hogg and Holden.[11])

The sphere

The pattern for this shape illustrates that likely to be obtained with a spherical gas holder or liquid-fuel container, filled by injection.

The hemisphere

This shape and the corresponding pattern may be related to the conditions existing in, say, the ignition hood of a sinter strand.

The cone

This shows the basic pattern to be expected in burner quarls fed with premixed air and gas.

The ellipsoid

This is not unlike certain types of OH furnace at the empty bath stage. It might, for example, be considered to apply to an OH furnace during fettling with a roughly horizontal burner setting.

The cylinder

The flow pattern in this shape is of particular interest industrially, since it applies to such radically different equipment as Lancashire boiler fire tubes, flame tunnels, and cement kilns, the flow patterns in most of which are particularly difficult to study in the actual plant. The problem of instability caused by the closing of the cylinder by the expanding jet has been noted by numerous workers. In the boiler field it can lead to the setting up of excessive vibration, while in a flame tunnel it has caused considerable difficulty owing to asymmetry, the flame at one time veering in one direction and then in another, but rarely if ever remaining on the central axis of the cylinder. Stability in such cases has been achieved by introducing a degree of asymmetry, e.g. in the method of introducing the air.

ACKNOWLEDGMENTS

The work described in this paper was carried out over a number of years, many people being concerned besides the authors. In particular we wish to refer to the assistance given by Messrs C. Holden, R. S. Howes, and M. J. McInerney. Our thanks are also due to Mr F. H. Saniter, Director of Research, for permission to publish this work.

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The effect of chemical composition on the shape of martensite transformation curves

R. Brook, M.Met., A. R. Entwisle, M.A., Ph.D., and E. F. Ibrahim, M.Met.

SYNOPSIS

The Greninger–Troiano technique was used to determine curves of % martensite v. *temperature for a number of iron–nickel–carbon, and iron–chromium–carbon steels. All the curves showed a linear region between about 5 and 55% transformation. The increment of transformation per °C in the linear range was found to be directly proportional to the M_S temperature. This relationship is shown to arise from a more general one, i.e. the increment of transformation per °C is proportional to the change in the thermodynamic driving force per °C.*

1789

INTRODUCTION

THE MARTENSITE TRANSFORMATION CURVES of many steels, where the transformation is 'athermal' have a similar shape.[1] The initial part of the plot of percentage martensite against temperature is curved and leads into a linear range between about 5 and 60% martensite. Beyond the linear range, the increment of transformation decreases as the temperature is lowered and approaches zero towards M_f. The increment of transformation per °C in the linear range will be termed the slope.

The main objective of the work described in this paper was to determine the effect of composition on the slope of the transformation curve, as defined above.

Grange and Stewart[2] have suggested that the temperature range between M_s and M_f is extended by an increase in carbon content, but little reliable information exists on the effect of composition on the slope. Fisher, Hollomon, and Turnbull[3] in their theoretical analysis of martensite transformations in steels, have shown a dependence of the shape of the transformation curve on carbon content, in qualitative agreement with Granger and Stewart. The work of Steven and Haynes[4] shows that in a number of low-alloy steels, the slope is relatively insensitive to composition.

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EXPERIMENTAL DETAILS

Sixteen steels with either nickel or chromium as the principal alloying element were manufactured in a high frequency induction furnace. The ingots were forged to $\frac{1}{2}$-in. dia. rod and homogenized at 1200°C for

TABLE I Composition of steels

Steel	C	Ni	Cr	Mn	Si
5N 6	0·58	5·18	0·01	0·03	0·25
5N 8	0·86	4·85	...	0·05	0·27
5N 10	1·02	4·79	...	0·05	0·16
5N 12	1·12	4·93	...	0·07	0·20
10N 6	0·57	10·06	...	0·04	0·19
15N 6	0·60	14·90	0·02	0·05	0·35
20N 6	0·61	19·76	...	0·07	0·73
13N 3	0·28	13·6	...	0·04	0·30
8CR 1	0·10	...	8·64	0·20	0·32
8CR 3	0·31	0·10	7·95	0·19	0·29
8CR 6	0·58	...	8·68	0·21	0·42
8CR 7	0·69	...	8·38	0·27	0·45
8CR 9	0·90	...	8·15	0·26	0·52
4CR 3	0·30	0·07	4·00	0·27	0·53
12CR 3	0·29	...	12·56	0·27	0·44
15CR 3	0·47	...	15·50	0·19	0·32

The % of sulphur lay within the range 0·016–0·028, phosphorus in the range 0·04–0·065, and molybdenum in the range 0·01–0·04.

three days. The analyses are given in Table I. The Greninger–Troiano[5] 'quench-temper' technique was adopted to investigate the course of transformation. Disc-shaped specimens $\frac{3}{8}$ in. dia. × $\frac{3}{16}$ in. thick were used for the nickel steels. The chromium steels were less homogeneous than the nickel steels, and to minimize the effects of longitudinal differences in composition, rather smaller specimens were used ($\frac{1}{4}$ in. dia. × $\frac{1}{8}$ in. thick). High temperature austenitizing was carried out in a nitrogen atmosphere. The nickel steels were nickel plated, and austenitized at 1100°C for 1 h giving an austenite grain size of ASTM 1. For the chromium steels treatments of between 25 and 55 min at 1200°C were used. This was sufficient to achieve complete solution of the carbides and gave a grain size of ASTM 1. The higher austenitizing temperatures of the chromium steels made an additional protection against decarburization desirable, this being provided by a carbon block situated in the furnace hot zone. In the case of the 0·1%C–8%Cr steel it was found that some carburization occurred at 1200°C and to avoid this a lower austenitizing temperature (1050°C) was used, the resultant grain size being between 1 and 2 ASTM. Metal quenching baths were utilized (Woods metal or mercury depending on the temperature required), except for the 20% nickel steel (M_s –11°C) which was quenched in methylated spirits with added solid carbon dioxide. The nickel steels were tempered at 300°C and the chromium steels at 500°C in a liquid metal bath.

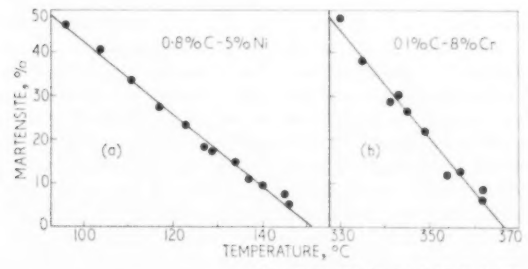
TABLE II Values of extrapolated M_s

Steel	M_s(°C)	Slope*	Conf. limits†	$\left[\frac{\partial \Delta F}{\partial T}\right]_m$ ‡	ΔF‖
5N 6	211	0·93	0·08	1·413	406
5N 8	151	0·82	0·02	1·320	406
5N 10	107	0·77	0·06	1·225	422
5N 12	88	0·81	0·10	1·178	417
10N 6	143	0·85	0·11	1·380	393
15N 6	62	1·04	0·09	1·235	373
20N 6	−11	0·91	0·09	1·137	329
13N 3	176	0·89	0·08	1·437	378
8CR 1	367	$1·21_5$	0·15	1·170	348
8CR 3	259	1·12	0·13	1·145	401
8CR 6	159	1·10	0·10	1·060	394
8CR 7	89	1·01	0·10	0·925	436
8CR 9	51	0·88	0·05	0·852	414
4CR 3	361	1·39	0·14	1·283	345
12CR 3	208	$1·01_5$	0·11	0·967	385
15CR 3	21	0·95	0·12	0·600	418

* % Martensite/°C.
† 95% confidence limits of slope.
‡ cals per mole/°C.
‖ cals per mole at M_s.

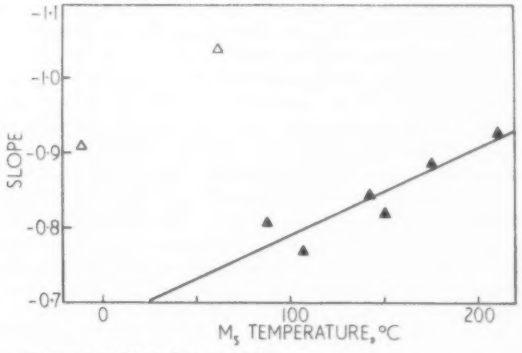
Steven and Haynes[4] have pointed out that both the quenching and tempering times must be sufficiently short to avoid the formation of lower bainite which on micro-examination would be indistinguishable from tempered martensite. It has been clearly shown that the formation of lower bainite is accelerated by the presence of martensite. For the steels with the shortest lower bainite incubation time, i.e. the lower carbon, lower alloy steels, the conditions of quenching and tempering were thoroughly investigated. Based on these findings quenching times of between 10 and 45 s and tempering times between 20 and 90 s were chosen, depending on the composition of the steel. The possibility of lower bainite formation was thereby eliminated. The estimation of the proportion of tempered martensite was made by a point-counting technique based on 1000 points per specimen and using a magnification of ×1500. A recent paper by Woodhead and Gladman[6] assesses the statistical accuracy of the technique.

Between 9 and 12 points spread between 5 and 55% transformation were determined for each steel. The best straight line through the points was calculated by the method of least squares and the appropriate statistical data determined (including the extrapolated value of M_s). In every case a good fit was



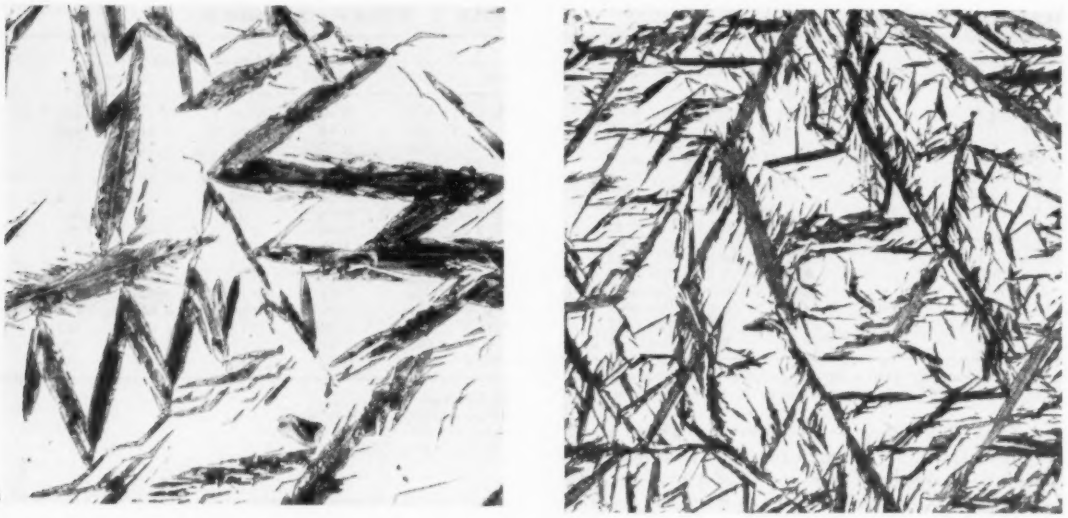
	(a) 0·8%C, 5%Ni	(b) 0·1%C, 8%Cr
Correlation coefficient r =	0·996	0·987
Regression coefficient b =	0·82	$1·21_5$
M_s (extrapolated) =	151°C	367°C
95% confidence limits of b =	±0·02	±0·15

1 *Typical graphs of martensite* v. *temperature. Graphs show the best and worst lines as judged by the 95% confidence limits of the slope* b



Slope = $1·167 \times 10^{-3}$ M_s + 0·675

2 *M_s temperature* v. *slope for nickel steels. The values indicated by the open symbols were not included when fitting the best straight line*



3 *Microstructures of (a) 20N6 and (b) 5N10 after quenching and tempering treatment. Change in shape and distribution of the martensite plates is clearly shown* ×250

obtained, and the best and worst lines (as defined by 95% confidence limits of the slope) are shown in Fig.1.

In addition to this metallographic method, the progress of transformation was investigated dilatometrically in certain of the steels. The steels with M_s above room temperature were cooled from the austenitizing temperature at about 20°C per min, through the transformation range. The 20% nickel steel ($M_s = -11$°C) was initially oil quenched, and then further cooled by immersion in acetone to which solid carbon dioxide was added. The rate of cooling in this case was about 5°C per min. The dilatometer specimens were 1 in. long and $\frac{5}{16}$ in. dia.

RESULTS

Nickel steels

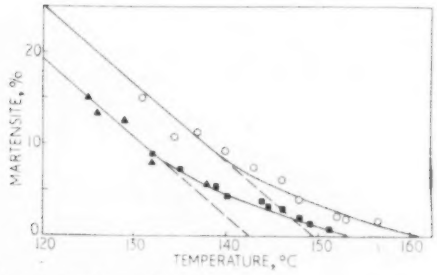
All the nickel steels studied showed a linear relationship between the approximate limits of 5 and 50% transformation. The values of the slopes of the linear relationships obtained are given in Table II, together with the 95% confidence limits of the slopes. These values of slope were plotted against carbon content, M_s, and nickel content and the best correlation was obtained against M_s, as shown in Fig.2. The open symbols indicate values of slope obtained for the 15 and 20% nickel steels and were not considered in the determination of the best straight line on the graph. 'Bursting' may interfere with the normal course of transformation in these two alloys, and this will be considered in more detail below. Since carbon has a strong influence on M_s and in view of the relationship established in Fig.2 it is obvious that there will be a correlation between carbon content and slope, and such a correlation was, in fact, obtained. Nickel, on the other hand, has a relatively weak effect on the M_s, and since the two high-nickel steels were excluded, no distinct correlation was obtained in the range of composition studied.

From the values of extrapolated M_s (Table II) the effects of carbon and nickel on the M_s were determined. The graphs of % nickel against M_s at constant C content (0·6%), and % carbon against M_s at constant Ni content (5%), gave good straight lines. The factors derived from these graphs for nickel and carbon were 15° and 225°C per 1% addition respectively. These compare with values of 17 and 474 given by Steven and Haynes.[4] However, it must be borne in mind that the alloys studied in this investigation were well outside the composition range studied by these authors.

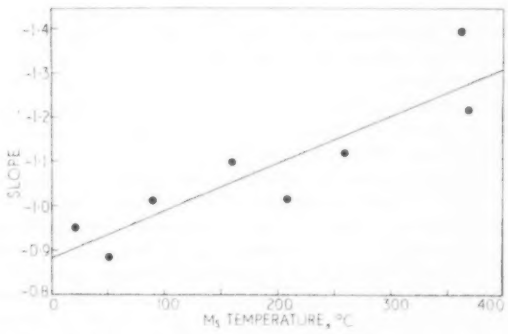
Although the steels in general showed typical martensitic structures, certain differences between them were noted. In the 15N6 and 20N6 steels the individual plates were thick, and there was clear indication of the co-operative 'zig-zag' formation of plates (Fig.3*a*). The structures of the remaining six alloys were all closely comparable having thin plates with no trace of 'zig-zag' formation (Fig.3*b*).

A simple dilatometer was used to study the effect of continuous slower cooling on the transformation in four of the alloys. The results obtained for the steels 5N6 and 5N8 showed close agreement with their metallographic equivalents. The steel 10N6 had a slope of −0·72 determined dilatometrically, compared with the −0·85 slope given by the metallographic investigation. It seems likely that this difference arises because of stabilization. The transformation range studied was between 140°C (M_s) and 80°C, and this is the range of temperature in which stabilization can occur most rapidly.[7] In the 20N6 alloy 'burst' formation of martensite was observed.[8] Bursts of approximately 15% martensite occurred at temperatures slightly below the M_s observed metallographically. It is for this reason, together with the metallographic differences reported above, that the values of slope determined by the 'quench-temper' technique for 15N6 and 20N6 were not considered along with the other results.

The initial non-linear portion of the transformation curve has been mentioned above, and it has been suggested that this curvature is caused by segregation in the steel.[2]



4 *Early stages of the transformation curve of 10N 6*



5 *M_s temperature* v. *slope for chromium steels*

It was necessary to determine the range of martensite formation over which this non-linearity existed, hence a detailed metallographic study was made of the first 10% of martensite formed in the steel 10N6. Figure 4 shows some of the data obtained. The left hand curve shows points from 'as-received' material (squares) and from material given a homogenizing treatment of three days at 1200°C (triangles). The right hand curve is for homogenized material from a different position in the initial ingot. It is quite clear that the shape of the non-linear region is not sensitive to the homogenizing treatment. The difference between the extrapolated M_s and the temperature at which transformation was first detected was about 12°C for both curves. The non-linear region extends up to about 7% transformation and specimens with less than this amount of transformation were excluded when determining the slopes given in Table II.

The nucleation of bainite by martensite was investigated metallographically and it was established that the metallographic results were not subject to interference by the formation of bainite. At the same time it was found that the nucleating effect of prior martensite formation on the bainite reaction in these steels, was comparable to that in the low-alloy steels used by Steven and Haynes. The presence of 25% martensite in 5N8 reduced the bainite incubation period by a factor of ×4, and 35% martensite in 5N6 caused a reduction of ×5. Steven and Haynes showed that the presence of 10 and 55% martensite reduced bainite incubation periods by factors of ×3 and ×7 respectively.

Chromium steels

The transformation curves for these steels further verified the existence of a linear relationship between 5 and 50% martensite. The slopes of the steels, along with the standard errors of the slopes and the extrapolated M_s are given in Table II. The most significant correlation resulted from a plot of extrapolated M_s against the slope of the steel, and this is shown in Fig.5. Good correlation was also observed between plots of carbon content versus slope (in 8%Cr alloys) and of chromium content versus slope (in 0·3%C alloys), but this is to be expected from the effects of carbon and chromium in lowering M_s, and in fact the observed relationships were in agreement with those predicted from Fig.5 and the carbon and chromium M_s factors.

The carbon content in the 8%Cr steels and the chromium content in 0·3%C steels (a correction being applied to the 15%Cr alloy) were plotted against extrapolated M_s temperatures. It was found that M_s was a linear function (within the limits of experimental accuracy) of chromium and carbon content. It was found that carbon lowered M_s 408°C per 1%C added and the chromium decreased M_s 22°C per 1%Cr added. These values are consistent with results of Klier and Troiano[9] which gave 380 and 22 respectively over a similar composition range. Steven and Haynes' factors of 474 and 17 are not in as good agreement, and this is probably due to the different composition ranges for which their formula is applicable. The carbon factor in these 8%Cr steels is very much greater than that observed for the 5%Ni steels mentioned above.

Microscopical examination showed a gradual change of structure according to the transformation range of the steel. A decrease in transformation temperature was accompanied by a thickening of the martensite plates and a coarser type of distribution. If the thicker plates formed at lower temperatures were examined at a high magnification, it could be seen that many could be resolved into an aggregate of very small plates.[10] In steels with lower transformation temperatures there was a tendency towards 'zig-zag' type of formation.

In order to determine whether different austenitizing temperatures would have a significant effect on the results, curves were determined for 4CR3 (which was austenitic over a wide temperature range) using austenitizing temperatures of 1200° and 1050°C for 30 min. This produced austenite grain sizes of ASTM of 1 and 2 respectively. The slopes of the two curves were not significantly different but a displacement occurred of about 6°C, transformation taking place at the slightly higher temperatures with the specimens austenitized at 1050°C. This displacement was in the opposite direction to that expected to result from the change in grain size. The difference was in the same direction as that observed by Harris and Cohen[1] but its magnitude very much less. Harris and Cohen attributed their change to a difference in the chemistry of the austenite at different temperatures.

DISCUSSION

In order to explain the details of the shape of the martensite transformation curve, a detailed theory of the kinetics of the transformation itself is needed. The theory of Fisher, Hollomon, and Turnbull[3], although

very detailed, is open to certain fundamental objections,[11] and it does not take into account the nucleation of new plates by plates already formed, which is thought to be an essential feature of the transformation. Furthermore, the theoretical transformation curves given by Fisher, Hollomon, and Turnbull in their paper, although they do show a change of slope with composition, are considerably more curved than the trend of the experimental points with which they are compared. The theory put forward by Philibert and Crussard[12] is not readily amenable to the quantitative determination of the transformation curve. We accept the experimental findings that when transformation is 'athermal', these curves have a linear region, and examine the factors which could affect the slope in this linear range. We do not propose, in this paper, to develop a theory of the kinetics of the transformation.

At any stage of the transformation, embryos for further transformation exist in the remaining austenite. If the temperature is lowered, some of these embryos become operative, and an increment of transformation results. The more embryos which become operative in a given fall of temperature (at a particular stage of the transformation) the greater is the increment. Since the number of embryos operated by a given fall of temperature depends on the free energy change, it is obvious that the increment of transformation will be some function of the temperature dependence of the free energy change. When the kinetics of transformation are such that the increment of transformation is constant over a range of temperature (i.e. the linear part of the curve), the temperature dependence of the free energy change should be an important factor controlling the slope. It therefore seemed appropriate to estimate the temperature dependence of the free energy change for the various steels, and correlate these values with the experimentally determined slopes.

Fisher[13] has proposed a formula for the free energy change for the martensite transformation in steels. Using the notation of Kaufman and Cohen's[11] recent review, this expression is:

$$\overset{\alpha'\to\gamma}{\Delta F} = x_{Fe}\overset{\alpha\to\gamma}{\Delta F_{Fe}} + x_C(-10500+3{\cdot}425\,T) - \Delta F^* + \sum\left\{x_A RT\ln\left(f_A^{\gamma}/f_A^{\alpha'}\right)\right\} \text{cals/mole} \quad \ldots\ldots(1)$$

where $\overset{\alpha'\to\gamma}{\Delta F}$ is the difference between the chemical free energy of austenite and martensite, and $\overset{\alpha\to\gamma}{\Delta F_{Fe}}$ is the difference in free energy between face-centred cubic and body-centred cubic iron. x_{Fe}, x_C, and x_A are the atomic fractions of iron, carbon, and substitutional alloying element A respectively. f_A^{γ} and $f_A^{\alpha'}$ are the activity coefficients of component A in austenite and martensite respectively. ΔF^* is the difference in free energy between the ordered and disordered arrangements of carbon atoms in iron.

$\overset{\alpha'\to\gamma}{\Delta F}$ is positive when martensite is the more stable phase.

Kaufman and Cohen,[14] and Kaufman,[15] have recently derived formulae for the free energy changes accompanying the martensite transformations in binary iron–nickel and iron–chromium alloys. These are:

Fe–Ni

$$\overset{\alpha'\to\gamma}{\Delta F} = (1-Z)\overset{\alpha\to\gamma}{\Delta F_{Fe}} + Z\,(-3700+7{\cdot}09\times10^{-4}T^2 + 3{\cdot}91\times10^{-7}T^3) + Z(1-Z)\,(3600+0{\cdot}58\,[1-\ln T]) \text{ cals/mole} \quad \ldots\ldots(2)$$

Fe–Cr

$$\overset{\alpha'\to\gamma}{\Delta F} = (1-Y)\overset{\alpha\to\gamma}{\Delta F_{Fe}} + Y\,(460+1{\cdot}0\,T) + Y\,(1-Y)\,(-2800+0{\cdot}75\,T) \text{ cals/mole} \quad \ldots\ldots(3)$$

where Y and Z are the atomic fractions of chromium, and nickel respectively. These equations have been incorporated into equation (1), instead of the term $\sum\left\{x_A RT\ln\left(f_A^{\gamma}/f_A^{\alpha'}\right)\right\}$; the following expressions then result:

Fe–Ni–C

$$\overset{\alpha'\to\gamma}{\Delta F} = x_{Fe}\overset{\alpha\to\gamma}{\Delta F_{Fe}} + x_{Ni}(-3700+7{\cdot}09\times10^{-4}\,T^2 + 3{\cdot}91\times10^{-7}T^3) + x_{Ni}x_{Fe}\,(3600+0{\cdot}58T\,(1-\ln T)) + x_C\,(10500+3{\cdot}425\,T) - \Delta F^* \text{ cals/mole} \quad \ldots\ldots(4)$$

Fe–Cr–C

$$\overset{\alpha'\to\gamma}{\Delta F} = x_{Fe}\overset{\alpha\to\gamma}{\Delta F_{Fe}} + x_{Cr}(460+1{\cdot}0\,T) + x_{Cr}x_{Fe}(-2800+0{\cdot}75\,T) + x_C\,(-10500+3{\cdot}425\,T) - \Delta F^* \text{ cals/mole} \quad \ldots\ldots(5)$$

where

$$\overset{\alpha\to\gamma}{\Delta F_{Fe}} = 1202 - 2{\cdot}63\times10^{-3}\,T^2 + 1{\cdot}54\times10^{-6}T^3 \text{ cals/mole} \quad \ldots\ldots(6)$$

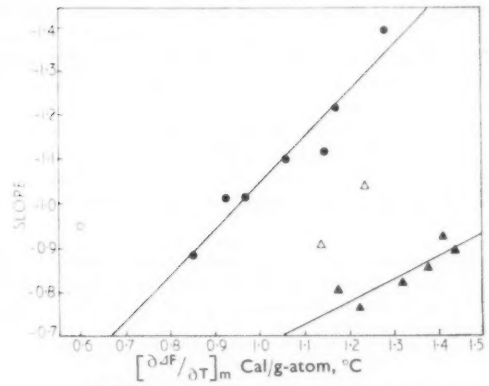
Because of the complex nature of the ΔF^* term, the equations (4) and (5) cannot be differentiated to obtain the temperature dependence of the free energy change, $\frac{\partial \overset{\alpha'\to\gamma}{\Delta F}}{\partial T}$. Therefore, values of $\overset{\alpha'\to\gamma}{\Delta F}$ were calculated for each steel at the extrapolated M_s, and at 20° and 40°C below M_s; a value of $\frac{\partial \overset{\alpha'\to\gamma}{\Delta F}}{\partial T}$ was then determined for each temperature interval, and the mean calculated. This mean value is indicated by the symbol $\left[\frac{\partial \overset{\alpha'\to\gamma}{\Delta F}}{\partial T}\right]_m$. $3\frac{\partial \overset{\alpha'\to\gamma}{\Delta F}}{\partial T}$ is not very temperature dependent. In all the steels except one, the difference in $\frac{\partial \overset{\alpha'\to\gamma}{\Delta F}}{\partial T}$ for the two 20°C intervals was less than 5%. The values obtained are given in Table II, and are shown graphically in Fig.6, where $\left[\frac{\partial \overset{\alpha'\to\gamma}{\Delta F}}{\partial T}\right]_m$ is plotted against the experimentally determined slope. In the case of the nickel steels, the 15 and 20% nickel alloys again lie well clear of the trend of the other points, and were excluded when calculating the best straight line. The same considerations lead to the exclusion of the 15%Cr alloy from the calculations. These three steels are indicated by the open symbols.

The equations of the regression lines are:

Fe–Ni–C $\quad \text{Slope} = 0{\cdot}518\left[\frac{\partial \overset{\alpha'\to\gamma}{\Delta F}}{\partial T}\right]_m + 0{\cdot}160 \quad r = 0{\cdot}938$, S.E.(b) = 0·096

Fe–Cr–C $\quad \text{Slope} = 1{\cdot}040\left[\frac{\partial \overset{\alpha'\to\gamma}{\Delta F}}{\partial T}\right]_m + 0{\cdot}005 \quad r = 0{\cdot}965$, S.E.(b) = 0·128

These correlation coefficients are highly significant and suggest a real dependence of slope on $\left[\frac{\partial \overset{\alpha'\to\gamma}{\Delta F}}{\partial T}\right]_m$.



6 *Slope* v. $\left[\frac{\partial\Delta F}{\partial T}\right]_m$ *for nickel steels* (▲, △) *and chromium steels* (●, ○). *Open symbols represent values excluded when fitting the best straight lines*

It is interesting to note that the line for the chromium steels, when extrapolated back, passes through the origin, which might be expected, since if $\left[\frac{\partial\Delta F}{\partial T}\right]_m$ is zero, no transformation can occur. The line for the nickel steels is less well defined, because the range of values of the variables is rather small. The intercept on the slope axis is appreciable, but in view of the statistical uncertainty of the line it may not be significant. The difference between the gradients of the lines is statistically highly significant. The reasons for this difference may lie in deficiencies in the thermodynamic analysis or in differences in the kinetics between the two groups of alloys.

If the equations (2) and (3) for the binary systems are accepted, then the major sources of error in the thermodynamic treatment are (*a*) no allowance is made for interaction between nickel or chromium and carbon (which is known to occur), and (*b*) uncertainty in the second term of equation (1), which is the term due to carbon. These errors should only be important when the alloy and carbon contents are high. This is because the temperature dependence of the first term in equations (4) and (5) is responsible for most of the change in $\Delta F^{\alpha'\to\gamma}$ with temperature. This term $x_{Fe}\overset{\alpha\to\gamma}{\Delta F_{Fe}}$ accounts for more than 80% of $\left[\frac{\partial\Delta F}{\partial T}\right]_m$. The dominance of this term also explains the correlation found between M_s and slope, (Figs.2 and 5). $\frac{\partial\overset{\alpha\to\gamma}{\Delta F_{Fe}}}{\partial T}$ falls steadily as the temperature is lowered (in the range of the M_s of the steels studied), and therefore $\left[\frac{\partial\Delta F}{\partial T}\right]_m$ falls correspondingly with M_s, when the alloy and carbon contents are not too high. Since a relationship has been established between slope and $\left[\frac{\partial\Delta F}{\partial T}\right]_m$, a similar but less precise relationship between M_s and slope must follow.

The values of driving force at M_s are given in Table II. These show a trend of increasing driving force with decreasing M_s, (about 20 cals per mole/100°C) similar to that reported for FeNi alloys, and FeCrNi steels. Again the 15 and 20%Ni steels are anomalous. The driving force is, however, much more sensitive to errors in the thermodynamic treatment than is $\left[\frac{\partial\Delta F}{\partial T}\right]_m$.

Three different kinetic factors have been observed in this work, which could affect the slope of the transformation curve. (*a*) Stabilization, which tends to decrease the slope. The slower cooling of the dilatometer specimens decreased the slope of 10N6 slightly, but had no effect on the other two steels examined. It is thought therefore that stabilization has had little effect, except possibly on the two steels highest in nickel. (*b*) Bursting was observed dilatometrically in one steel (20N6) and may have occurred to a lesser extent in two others, judged by metallographic examination. No distinct signs of bursting were observed on the transformation curves determined metallographically. It is unlikely that the slope of a steel in which bursting occurs will follow the same trend as the steels free from bursting, because of the different kinetics involved. (*c*) Any difference in the shape of the martensite plates between one steel and another may lead to a difference in the slope. The two highest nickel steels were found to have much thicker plates than the other nickel steels. A similar but much less marked change was noted in the highest chromium steel.

Of the factors mentioned above, deficiencies in the thermodynamic treatment, or differences in the shapes of the martensite plates, are the most likely reasons to account for the differences between the two lines in Fig.6. There may, however, be a more fundamental explanation. It should be noted that all these kinetic and thermodynamic effects which might be expected to upset any correlation between slope and $\left[\frac{\partial\Delta F}{\partial T}\right]_m$, are most likely to manifest themselves at low temperatures (100°C), i.e. at higher carbon and alloy contents. It is just these steels which do not fit in with the general correlations established in Figs.2, 5, and 6.

Consideration must be given to the results of Kaufman and Cohen[14] on binary iron–nickel alloys. These indicate that the slopes of the transformation curves *increase* with falling M_s (i.e. increasing nickel content), contrary to the trends shown in Figs.2 and 5. The values of $\frac{\partial\Delta F}{\partial T}$ at M_s for these alloys (calculated from equation (2)) *increase* with falling temperature up to about 20%Ni and therefore the correlation between slope and $\frac{\partial\Delta F}{\partial T}$ is still valid. This emphasizes the fact that the correlations between slope and M_s are dependent on the details of the thermodynamic quantities involved, whereas the correlation between slope and $\left[\frac{\partial\Delta F}{\partial T}\right]_m$ is the more general one. The higher nickel alloys of Kaufman and Cohen showed bursting and are excluded from consideration in this context.

CONCLUSIONS

(1) The martensite transformation curves of a range of iron–nickel–carbon and iron–chromium–carbon alloys are linear in the range 5–55% transformation.

(2) Within the limits of composition studied, the

slope of the transformation curve can be represented approximately as a linear function of M_s (slightly different functions for the nickel and chromium steels). There are some anomalies when the M_s is below about 60°C (i.e. high alloy and carbon contents).

(3) The slope of the transformation curve is proportional to the thermodynamic function $\frac{\partial \Delta F^{\alpha' \rightarrow \gamma}}{\partial T}$

although nickel and chromium steels give different correlations. There are again some anomalies in steels with high alloy and carbon contents. The relationship between M_s and slope follows from this correlation.

(4) In the composition range studied, the effects of nickel and chromium on M_s are comparable with the effects in low alloy steels. Carbon is found to be much less effective in the nickel steels and somewhat less in the chromium steels than in low alloy-steels.

ACKNOWLEDGMENTS

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The effects of hydrogen on the mechanical properties of low-alloy rotor forging steels

R. M. Goldhoff, S. Yukawa, and J. G. McMullin

INTRODUCTION

THE PROBLEMS associated with residual hydrogen from the steelmaking process which have been of major concern to the producers and users of large forgings are: (a) flaking, (b) loss of ductility associated with moderate hydrogen contents, and (c) the phenomenon of delayed failure.

In the last few years, the adoption of vacuum-pouring techniques has effectively eliminated the problems associated with residual hydrogen. However, the experimental work described in this paper was undertaken before vacuum-poured forgings became widely available. Information on four points was sought in

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SYNOPSIS

The effect of hydrogen in low-alloy forging steel is studied with respect to (a) *the relationship between embrittlement induced by laboratory methods and that present in large air-poured forgings containing hydrogen,* (b) *its effect on notched properties,* (c) *the degree to which vacuum-poured steel is susceptible to embrittlement, and* (d) *delayed failure characteristics.*

It is concluded that (a) *the loss of ductility due to hydrogen embrittlement is greater for the steel charged artificially than for the same steel containing residual hydrogen from the steelmaking process,* (b) *there is a considerable loss of both notched strength and ductility as a result of the presence of hydrogen,* (c) *vacuum-poured steel is susceptible to hydrogen embrittlement but less so than air-poured steel, and* (d) *delayed fracture phenomena are operative in these low-strength steels.* 1786

TABLE I Composition and heat-treatment of steels used in hydrogen studies

(a) *Chemical composition*

Steel	C	Mn	P	S	Si	Ni	Cr	Mo	V
A	0·29	0·34	0·017	0·021	0·25	3·50	1·80	0·35	...
B	0·32	0·78	0·035	0·037	0·21	0·17	1·11	1·18	0·24
C	0·30	0·67	0·020	0·014	0·25	2·40	...	0·51	0·08
D	0·22	0·59	0·011	0·012	0·17	2·83	0·14	0·49	0·07
E	0·26	0·67	0·028	0·027	0·25	2·88	0·34	0·54	0·07
F	0·26	0·54	0·015	0·025	0·24	2·66	0·09	0·50	0·10
G	0·25	0·60	0·028	0·030	0·14	2·54	0·09	0·51	0·10
H	0·31	0·72	0·022	0·031	0·20	2·51	0·06	0·52	0·09
I	0·30	0·48	0·031	0·031	0·22	2·60	0·05	0·44	0·09

(b) *Heat-treatment*

Steel	Austenitize	Temper
A (≠1)	5 h, 927°C (1700°F), F.C.†	16 h, 704°C (1300°F), F.C.
A (≠2)	5 h, 871°C (1600°F), F.C.	30 h, 621°C (1150°C), F.C.
B*	42 h, 1010°C (1850°F), A.C.† to 232°C (450°F), hold 12 h	12 h, 666°C (1230°F), F.C.
C*	32 h, 871°C (1600°F), A.C.	40 h, 616°C (1140°F), F.C.
D*	42 h, 843°C (1550°F), A.C.	50 h, 638°C (1180°F), F.C.
E*	35 h, 843°C (1550°F), A.C.	20 h, 649°C (1200°F), and 20 h, 649°C (1200°F), and 32 h, 660°C (1220°F)
F*	20 h, 799°C (1470°F), A.C.	40 h, 630°C (1165°F), F.C.
G*	40 h, 843°C (1550°F), A.C.	60 h, 582°C (1080°F), F.C.
H & I	4 h, 954°C (1750°F), A.C. & 4 h, 810°C (1490°F), F.C.	8 h, 638°C (1180°F), F.C.

(c) *Type*

A = forged and cross-rolled ingot
B, C, D, E, G = air-poured rotors
F = vacuum-poured rotor
H, I = respectively the electrode and finished ingot of a consumable-electrode process heat

*Specimens taken directly from slabs integral with finished forgings.
†F.C. = furnace cool; A.C. = air cool.

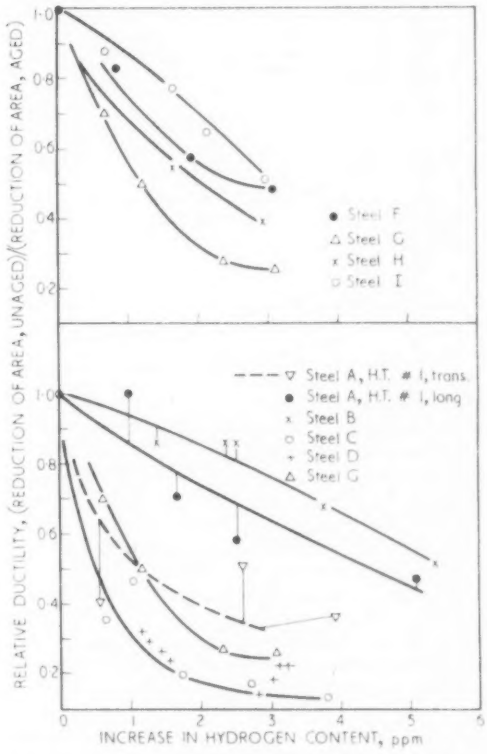
this work: (a) effect of residual hydrogen from processing *v.* hydrogen introduced by laboratory charging, (b) effect of hydrogen on notched properties, (c) response of vacuum-poured and air-poured steels when charged to equal hydrogen content, and (d) delayed failure characteristics of these medium strength steels (120000 lb./in² tensile).

These questions deal with hydrogen embrittlement only; the flaking problem was not included in the investigation.

EXPERIMENTAL PROCEDURE

The relationship between tensile ductility and hydrogen content was compared for air-poured steels artificially charged with hydrogen and specimens of the same steel trepanned directly from large forgings. Statistical means were adopted to evaluate these relationships. The same comparison was made for steels of similar composition and heat-treatment but which had been vacuum-poured in one case and prepared by the consumable-electrode process in another case. The effect of hydrogen on the notched properties of air-poured steels was determined by tensile and slow bend tests of specimens charged under controlled conditions. Lastly, the delayed fracture phenomenon was evaluated using static stress-rupture tests at room temperature and again using an artificial charging method. Test bars of a size sufficient to retain substantial amounts of hydrogen for long periods were used. Table I gives an adequate description of all the materials used in this investigation.

Controlled hydrogen charging of specimens was accomplished by heating below the final tempering temperature in a pressurized hydrogen atmosphere. The simple apparatus used consists of a specimen container which is welded shut, evacuated, pressurized with hydrogen, and placed in a furnace. After heating, the container is water quenched, the end sawed off quickly, and the specimens rapidly cooled to room temperature for immediate testing. Standard experimental conditions of 2 h heating at 625°C (1160°F) in hydrogen up to 30 atm were adopted. The basis for comparison was an aged specimen given an identical thermal cycle in an argon arc atmosphere. Variations in hydrogen pressure controlled the final gas content.



1 *Effect of hydrogen increase on relative ductility in smooth tensile test*

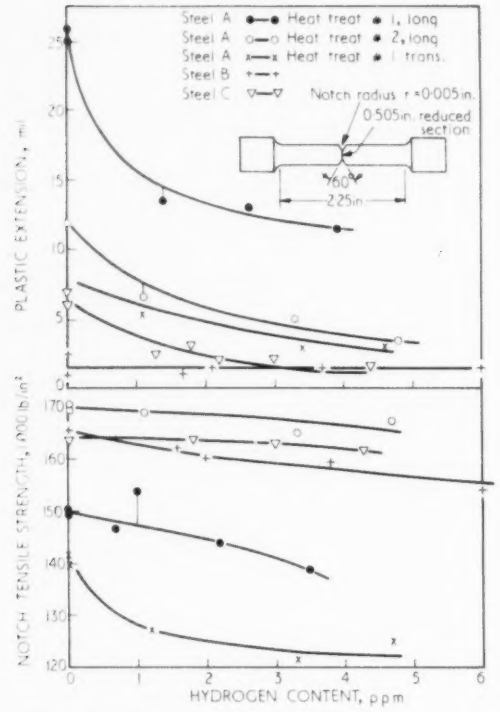
Hydrogen analyses were made by a hot vacuum-extraction technique which, after some experimentation, appeared to compare favourably with other analytical methods in current use.

All the standard precautionary measures involved in testing and trepanning specimens for hydrogen effects were observed.[1]

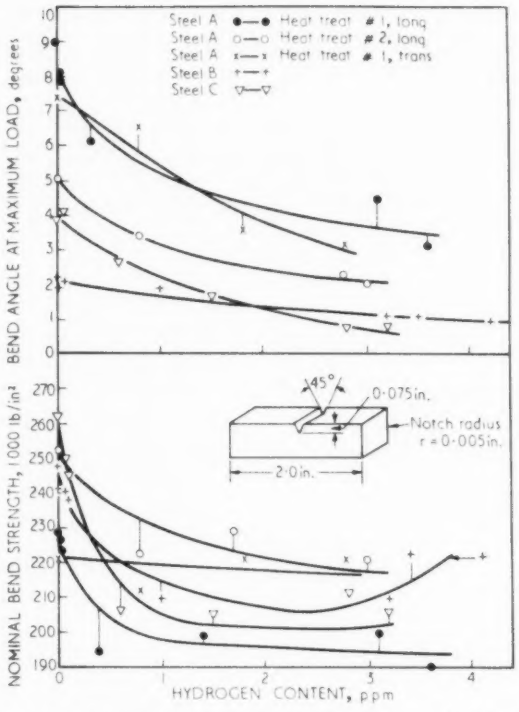
EXPERIMENTAL RESULTS: ARTIFICIAL CHARGING

Smooth tensile tests

Results were obtained on both longitudinal and transverse specimens of Steel A, as well as specimens cut radially from the large forgings of Steels B, C, D, F, G, H, and I. In Fig. 1 the relative ductility (ratio of unaged to aged reductions of area) is plotted against the increase in hydrogen content. The increase is determined by the difference between the charged and aged hydrogen contents. It was observed, as in past work, that hydrogen apparently has little or no effect on tensile strength, yield strength, or modulus of elasticity as ordinarily measured.[2]


Steel A ●—● Heat treat # 1, long
Steel A ○—○ Heat treat # 2, long
Steel A x—x Heat treat # 1 trans.
Steel B +—+
Steel C ▽—▽
Notch radius r = 0·005in.
0·505in. reduced section
60°
2·25in.
PLASTIC EXTENSION, mil
NOTCH TENSILE STRENGTH, 1000 lb/in²
HYDROGEN CONTENT, ppm

2 *Effect of hydrogen content on ductility and strength in 0·505-in. dia. notched tensile specimens*


Steel A ●—● Heat treat # 1, long
Steel A ○—○ Heat treat # 2, long
Steel A x—x Heat treat # 1, trans
Steel B +—+
Steel C ▽—▽
BEND ANGLE AT MAXIMUM LOAD, degrees
NOMINAL BEND STRENGTH, 1000 lb/in²
45°
0·075in.
Notch radius r = 0·005in.
2·0in.
HYDROGEN CONTENT, ppm

3 *Effect of hydrogen content on ductility and nominal bend strength in ⅜-in. square notched slow bend specimens*

Notched tensile tests

The ductility value chosen for comparison in this test was the plastic extension at fracture. This value is obtained from the load-extension diagram by subtracting the elastic portion from the total extension. The effects of hydrogen on notched ductility and strength are shown in Fig.2.

Slow notched bend tests

Load deflection data were obtained using a dial indicator to measure the head movement of the tensile machine. The values of bend angle calculated from deflection measurements at the maximum load were used as the comparative ductility criterion. Likewise, the comparison of bending strengths was made on the basis of calculations involving maximum observed loads. Simple beam formulas were used in all these calculations. The deflection values reported are the plastic components analogous to the notched tensile ductility values obtained as described previously for notched tensile tests. Figure 3 shows the effect of hydrogen on strength and ductility in this test.

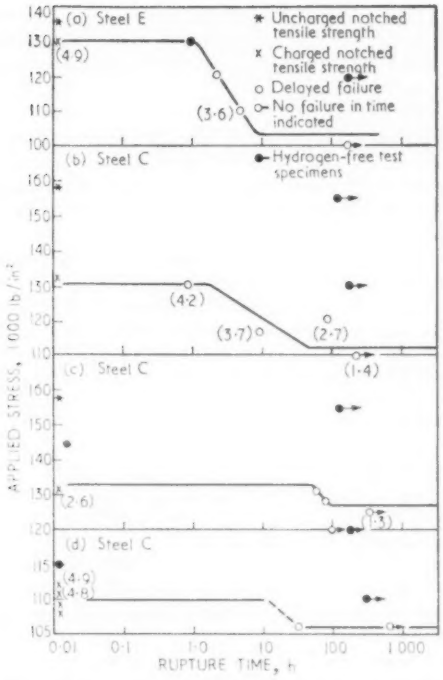
Delayed fracture tests

The effect of hydrogen on time-dependent fracturing in high-strength steel has been investigated.[3–5] Results of the present work using Ni–Mo–V steels are shown in Fig.4. The curves compare the effects of uncharged notched strength level, hydrogen content, and the presence or absence of notches on the phenomenon of delayed failure in these steels.

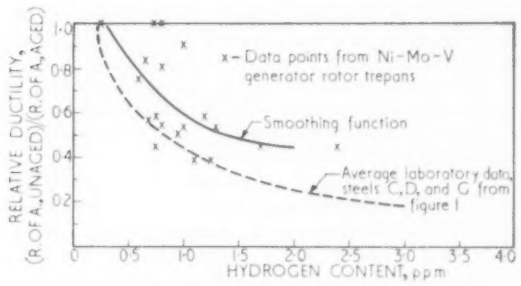
EXPERIMENTAL RESULTS: FORGING TREPANS

For a number of years, all Ni–Mo–V forgings were subject to a quality check for hydrogen content and tensile ductility. As explained previously, trends in these data were evident but the accompanying scatter and lack of precise correlation between hydrogen content and tensile ductility became a matter of concern. Subsequent laboratory work showed much better correlation of hydrogen content and ductility, but the two trends were not comparable. Laboratory data tended to show a much larger loss in tensile ductility in the interesting hydrogen range from 0·5–1·5 ppm than did similar data obtained from forging trepans.

To illustrate this problem, data from 19 generator forgings are shown in Fig.5. The material is Ni–Mo–V of the composition shown in the report and is representative of one continuous six-month period of production by several mills. Plotted in the figure is the relative ductility (as defined previously) against hydrogen content. A precise correlation is obviously lacking. The correlation could not be improved by considering tensile strength level as a separate parameter. To gain a better understanding of these results, a programme of statistical analysis based on ratios of aged and unaged ductility was undertaken. For the data shown the hydrogen values alone proved more amenable to correlation with ductility than combinations of tensile strength and hydrogen values. The equation exhibiting the lowest value of standard deviation was used to draw the smooth curve appearing in Fig.5. A similar curve, based on an average of the air-poured Ni–Mo–V data, is included to compare the laboratory data with the trepan data.



4 *Delayed-failure curves for charged, notched* (a, b, c), *and smooth* (d) *specimens of steel C and E at room temperature.*


x – Data points from Ni-Mo-V generator rotor trepans
Smoothing function
Average laboratory data, steels C, D, and G from figure 1
RELATIVE DUCTILITY, (R.OF A.UNACED)/(R.OF A.ACED)
HYDROGEN CONTENT, ppm

5 *Comparison of hydrogen/tensile ductility correlation between laboratory data and forging trepan data*

DISCUSSION

The points originally set down will not be considered individually.

It is clearly seen from examination of Fig.5 that the loss of ductility due to hydrogen embrittlement is greater for the steel charged artificially than for the same steel containing residual hydrogen from the steelmaking process. Further, it appears that artificial charging allows for more precise correlation between hydrogen content and ductility. Considering the care taken in sampling forgings and in subsequent analysis, it is unlikely that errors in these techniques can in themselves account for the large differences noted. In some sense then, the specimens trepanned from a rotor and containing residual hydrogen must differ from a laboratory specimen charged with a like amount of hydrogen. An explanation of this observation can be deduced from recent concepts of hydrogen embrittlement as stated by Morlet *et al.*[6]

These authors have postulated that the magnitude of observed embrittlement is dependent on the steady-state distribution of hydrogen, and any change therein should affect the degree of embrittlement. Since the rotors sampled in this work were forged, heat-treated, and held for weeks at room temperature before testing, it is not hard to visualize a steady-state hydrogen distribution for them which is different from that of a freshly charged specimen. In fact Morlet infers that hydrogen charged into a specimen is probably in a different form, i.e. in solution, from that carried through the steelmaking process. Another of their conclusions is that embrittlement results from hydrogen in solution and that hydrogen contained in voids is non-damaging. If so, then the overall hydrogen content reflected by the analyses, particularly in the case of forging trepans, cannot be used as an accurate measure of the hydrogen detrimental to ductility. In part, this could account for the lack of accurate correlation observed in this study for the hydrogen content/ductility relationship.

The chief mechanical property of steels affected by hydrogen is the capacity for plastic deformation. In general, the detrimental effects occur primarily in the presence of complex stresses. Since machine components normally operate under complex stress conditions, it is well to evaluate material characteristics with this in mind. Notched tests, such as were employed here, are at least indicative in this sense. Thus, both strength and ductility losses of considerable magnitude are evident for Ni–Mo–V and Cr–Ni–Mo steels when charged artificially. There appears to be practically no effect in the Cr–Mo–V steel, but this might be expected since its inherent notched ductility is very low.

Although the data are admittedly meagre, it is evident that the Ni–Mo–V composition studied here after vacuum pouring or after processing by the consumable-electrode method is still susceptible to hydrogen embrittlement. However, the ductility losses suffered appear to be much less, particularly in the 0–2 ppm range. One explanation of this observation is embodied in the 'permanent damage' concept. This concept presumes that hydrogen originally introduced in melting and pouring will persist through subsequent treatments in large forgings to produce some sort of permanent damage. While there does not appear to be firm evidence to preclude this theory, there is need for considering the effect on hydrogen embrittlement of such factors as the amount and distribution of inclusions in the steel. In particular, the lower susceptibility noted for the consumable-electrode melted steel is interesting because the main difference between this steel and others may well be in the size, distribution, shape, and perhaps amount of non-metallic inclusions. Further supporting evidence in this respect can be taken from Fig.1 where it is shown that transverse specimens of the Cr–Ni–Mo steel are much more susceptible to hydrogen embrittlement than those taken longitudinally. Here again the major difference is probably in the disposition of the stringer-like inclusions. In the transverse specimens, these are more likely to be normal to the stress direction thus providing areas of high stress-concentration leading to easier crack initiation.[7]

It is interesting to note that Morlet *et al.*[6] have also

theorized that hydrogen will exert its maximum embrittling effect in the region of most severe triaxial stresses. It is evident that such a postulate is not at all inconsistent with the foregoing observations and remarks, since inclusions in steels do present varying degrees of triaxial stress-concentration depending on their shape and distribution.

The most important observation to be made concerning the delayed-fracture tests is that the phenomenon can also occur in these relatively lower strength steels. In a general way, the results follow the behaviour established for higher strength steels. The addition of hydrogen lowers the notched tensile strength, and there is a narrow but well defined critical-stress range for delayed fracture. Differences in strength seem to have little effect, but reducing the hydrogen content narrows the critical stress range. Changing from a notched to a smooth bar all but eliminates the phenomenon. Of importance here is the fact that the lower critical stresses for delayed fracture in the lower strength steel exceed the yield strength, whereas the converse is true for the high-strength steels.

SUMMARY

Even though it has been shown that the actual detrimental effect of hydrogen in embrittling alloy forging steels is probably not as drastic as might be predicted from controlled laboratory tests, the need for its reduction is evident. To this extent, it is noteworthy that the adoption of vacuum pouring for large rotor forging ingots has relieved the problems formerly associated with residual hydrogen contents.

ACKNOWLEDGMENT

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Note: When this paper was written, the authors included information and expressed opinions believed to be correct and reliable. Because of the constant advance of technical knowledge, the widely differing conditions of possible specific application, and the possibility of misapplication, any application of the contents of this paper must be at the sole discretion and responsibility of the user.

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Counting non-metallic inclusions in steel

J. V. Hardy and R. T. Allsop

INTRODUCTION

ONE OF THE MORE DIFFICULT ASPECTS of quality control in steelworks is the assessment of non-metallic inclusion contents. Methods for the estimation of inclusions comprise separation by chemical or electrolytic processes, macroscopic examination, and counting with the aid of a microscope. Both chemical and electrolytic separation require specialized apparatus and techniques and are quite impracticable in the average steelworks, although they can be usefully employed in a research laboratory. The macroscopic methods, such as the fracture of hardened testpieces or magnetic ink techniques, require careful interpretation of the results and are generally incapable of distinguishing between various types of inclusions. Routine examination for inclusion contents is therefore generally carried out by means of a microscopic counting method. The purpose of the present paper is to examine to what extent the commonly used microscopic techniques are capable of giving reproducible results, to consider a new method for counting inclusions, and to determine the effect of variations in mechanical reduction on an inclusion count.

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SYNOPSIS

Three popular methods for counting inclusions were shown experimentally to give very poor reproducibility between different observers. The reasons for this are discussed. A new simplified counting method was shown to give improved reproducibility provided that the degree of personal judgment required from the observer was kept to a minimum. The effect of mechanical working on the results of the inclusion count is also examined. 1790

Reproducibility of three inclusion counting methods

To determine to what extent the commonly employed inclusion-counting techniques are capable of giving reproducible results, an experiment was carried out using the SAE, Jernkontoret (JK), and Fox counting methods.

Experiment

A cast of steel was sampled and billets representing the top, middle, and bottom of selected ingots were sectioned and prepared for micro-examination in the manner recommended for each of the three counting methods. It is considered unnecessary to describe the operation of these counting methods since they are widely used and have only recently been reviewed in detail by Allmand.* The counts were performed by microscopists in separate laboratories. In each case the conditions under which the inclusion counts were carried out were carefully standardized. Thus, such things as magnification and field diameter were fixed and each observer performed the counts on the same polished surfaces.

Results

Owing to administrative difficulties it was not possible to obtain a full set of results for each microscopist, but sufficient were obtained to enable comparisons to be made, and these are shown in Tables I–III.

The results showed generally very poor agreement between different observers. The SAE count showed the largest scatter of results, and it was notable that not even the length and nature of the longest inclusion could be decided. With the JK count, not only was there lack of agreement with respect to total inclusions but also with respect to the relative proportions of different types of inclusions. The results of the Fox count, previously considered by the microscopists involved to be the most reliable method, showed that it was little better than the SAE or JK counts.

Reasons for poor reproducibility

Throughout the experiment care was taken to ensure that the experimental conditions were completely standardized. Nevertheless the results indicate that there was little agreement between the various observers. It must be concluded, therefore, that the variations in inclusion contents recorded were due to the inability of some, if not all, of the observers involved to perform the tests accurately. Reasons why this is so appear to be mental fatigue and differences in personal judgment between observers. Regarding fatigue there can be little doubt that during the course of an inclusion count observers do become mentally weary as a result of the rather uninteresting and repetitive nature of the task. Several of the microscopists involved in the experiment commented on this point.

In each counting method, in addition to the more arithmetical aspects of the test, each observer has to exercise some degree of judgment, e.g. in the case of the SAE count the observer has to decide the length of the longest inclusion. The longest inclusion in this context does not mean simply the longest unbroken inclusion; strings or groups of particles may also be assessed as 'single' inclusions. Obviously, therefore, it is difficult for the observer to decide the limits of each inclusion and then select the longest. In these circumstances it seems inevitable that the conclusion reached independently by one observer will frequently differ from that of another.

The assessment of the general background level of inclusions by the SAE method is performed by comparing the background inclusion pattern with a series of standard charts. This procedure is similar to those required for the Fox and JK counting methods except that in the latter counts the observer also has to assess separately the various types of inclusions, e.g. sulphides, silicates, etc. With the SAE count only the pattern of small background inclusions must be compared with the standard charts, all the larger inclusions which are counted separately being excluded from the assessment. Similarly, with the JK and Fox methods the pattern of each type of inclusion observed in the microscope must be separately compared with the standard charts. It is considered that variations of personal judgment in performing the basic task, i.e. the repeated comparison of microscopical fields of view with standard charts and the selection of the chart most closely in accord with each field, will give rise to some degree of variation in the inclusion counts recorded by different observers. When in addition to the basic task the observer is required to exclude certain elements in a field of view and compare only the remainder with the standard charts then it is considered that large variations between observers are possible.

From the foregoing discussion it would appear that the type of inclusion count most likely to give reproducible results is one which is simple and which requires little or no personal judgment on the part of the operator. A new counting method was devised which was considered to fulfil these requirements.

TABLE I Results of Fox counts

Ingot no.	Specimen position	Operator 1	2	3	4	5	6	7
1	Top	105	94	126	142	181	205	148
	Middle	93	93	90	142	157	197	143
	Bottom	101	101	150	126	188	193	149
5	T	85	109	...	...	165	141	123
	M	87	118	...	...	203	124	126
	B	82	121	...	...	191	122	104
9	T	83	120	106	146	150	134	163
	M	71	108	92	131	126	122	143
	B	79	123	141	183	139	157	175
13	T	62	99	110	141	180	166	126
	M	68	112	83	148	218	190	129
	B	61	129	114	156	203	187	132
17	T	106	114	...	152	185	161	134
	M	91	124	...	140	194	159	133
	B	108	111	...	122	168	162	107
21	T	56	114	109	139	164	132	120
	M	37	106	82	135	144	128	69
	B	43	115	116	136	171	149	106
25	T	87	126	76	147	159	150	103
	M	90	106	84	143	137	138	100
	B	107	133	112	160	162	139	135

THE LINEAL-TRAVERSE INCLUSION COUNT

The lineal-traverse count is a new microscopic counting method which enables inclusions to be counted individually. The specimen to be examined is prepared by taking a longitudinal section of a bar or billet as in the JK count. After polishing, the specimen is examined at a magnification of ×90–100 with a microscope provided with a mechanical stage and crosswires in the eyepiece. The exact magnification is not critical but should not be much higher than the range specified, otherwise very small inclusions are observed and the counting becomes tedious.

The specimen is traversed at right angles to the rolling direction and all inclusions intercepted by the intersection of the crosswires are counted (Fig.1). A measured distance is traversed, made up from several

* T. R. Allmand: *JISI*, 1958, **190**, 359–372.

TABLE II Results of JK counts. Averages with respect to 100 fields of view

Ingot no.	Specimen position	Operator 1	2	3	4	5	6
1	T	1·02, 0, 0·75, 0	1·54, 0, 1·25, 1·17	1·87, 0, 1·07, 0		1·4, 0, 1·2, 0·85	0·90, 0, 0·27, 0·11
	M	0·70, 0, 0·71, 0	1·46, 0, 1·10, 1·08	1·85, 0, 1·00, 0		1·44, 0·01, 0·78, 0·41	0·88, 0, 0·21, 0·06
	B	0·95, 0, 1·23, 0	1·82, 0, 1·05, 1·60	1·57, 0, 1·49, 0		1·62, 0·03, 1·08, 0·44	1·03, 0, 0·46, 0·09
5	T	0·69, 0, 0·82, 0	1·15, 0, 0·03, 0·55				1·05, 0, 0·53, 0
	M	0·47, 0, 0·55, 0	0·97, 0, 0·07, 0·36				1·07, 0, 0·36, 0
	B	0·47, 0, 0·46, 0	1·27, 0, 0·34, 0·08				1·19, 0, 0·39, 0
9	T		2·0, 2·0, 2·0, 1·0	1·17, 0, 1·04, 0	1·1, 0, 1·5, 0		0·78, 0, 0·43, 0
	M			0·96, 0, 1·42, 0	1·0, 0, 1·9, 0		0·95, 0, 0·61, 0
	B			0·84, 0, 1·64, 0	1·2, 0, 2·0, 0		1·37, 0, 0·36, 0
13	T			1·67, 0, 1·01, 0		1·25, 0, 1·18, 0·62	1·23, 0, 0·32, 0·18
	M			1·95, 0, 1·40, 0		1·36, 0·10, 0·78, 0·27	1·03, 0, 0·19, 0·04
	B			1·49, 0, 1·50, 0		1·62, 0·08, 1·18, 0·24	0·98, 0, 0·70, 0·07
17	T	1·13, 0, 0·91, 0		1·61, 0, 0·24, 0			1·1, 0, 0·05, 0
	M	1·04, 0, 0·87, 0		1·32, 0, 0·28, 0			1·4, 0, 0·24, 0·05
	B	0·91, 0, 1·1, 0		1·20, 0, 1·78, 0			1·5, 0, 0·28, 0·08
21	T			1·51, 0, 0·67, 0	1·5, 0, 0·8, 0	1·27, 0, 1·02, 0·43	0·93, 0, 0·05, 0·42
	M			2·08, 0, 0·49, 0	1·4, 0, 1·2, 0	1·92, 0, 0·46, 0·63	0·82, 0, 0·15, 0·25
	B			1·41, 0, 1·47, 0	1·2, 0, 1·4, 0	1·38, 0, 1·03, 0·61	1·05, 0, 0·96, 0
25	T	0·84, 0, 0·84, 0		1·77, 0, 0·79, 0	1·2, 0, 0·7, 0	1·36, 0, 0·88, 0·47	0·68, 0, 0·27, 0
	M	0·74, 0, 0·76, 0		1·81, 0, 1·26, 0	1·3, 0, 1·0, 0	1·32, 0, 0·84, 0·69	0·90, 0, 0·50, 0
	B	1·08, 0, 1·56, 0		1·59, 0, 2·14, 0	1·1, 0, 1·4, 0	1·41, 0, 1·48, 0·77	0·86, 0, 1·06, 0

runs to cover the area of the specimen, and the inclusion count is expressed as the number per unit length of the traverse. The unit usually employed is inclusions per centimetre. For most steel specimens a total traverse length of 10–20 cm has been found by statistical analysis to be sufficient.

Experiment

An experiment was performed to determine the reproducibility obtainable with this counting method when the same metallographic surfaces were examined by a number of microscopists. Seven steel specimens covering a wide range of inclusion contents were prepared. The magnification employed was ×90 and the total traverse length was 10 cm for each specimen.

Results

The results, corrected to the nearest whole number, are presented in Table IV from which it appears that the reproducibility is of a high order.

Statistical analysis of these results showed that the range of inclusion numbers for any specimen could be roughly described by the expression

$$r \pm 2\sqrt{\frac{r}{l}}$$

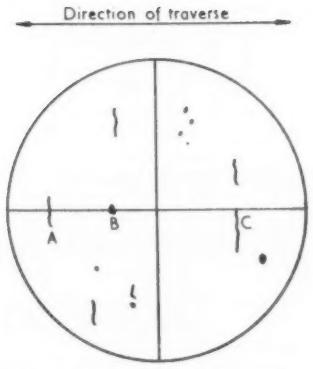
where r is the average inclusion number (inclusions per cm) and l is the total traverse length surveyed. This dependence of the accuracy upon the population density and the amount of inspection is usually the case when random events are counted. The fact that the experimental results agree so nearly with statistical theory in this instance leads to the conclusion that the scatter in the results is mostly due to the random occurrence of the inclusions rather than the personal error of the operators. In other words, the results for different operators measuring the inclusion number of the same specimen differ by no more than would the results of repeated tests on the specimen by one operator.

The relatively high degree of reproducibility obtained in the above experiment confirms that a simple inclusion count which requires little personal judgment on the part of the observer is capable of giving reproducible results between observers in separate laboratories. It is of interest to examine what happens to the reproducibility of this counting technique when the degree of personal judgment required from the observer is increased by asking him to identify different kinds of inclusions and count them separately.

Two metallographic specimens were examined by the group of observers. The types of inclusions present

TABLE III Results of SAE counts

Ingot no.	Specimen position	Operator 1	2	3	4	5	6	7
1	T	5^{d}-$1{\cdot}39^{191}$-B	4^{vd}-$1{\cdot}71^{76}$-C	5^{dT}-$1{\cdot}85^{87}$-C	6^{d}-$1{\cdot}0^{16}$-B	6^{d}-$1{\cdot}4^{268}$-C	4^{d}-$2{\cdot}28^{26}$-B	7^{vd}-$1{\cdot}8^{32}$-B
	M	5^{d}-$1{\cdot}41^{106}$-B	4^{vd}-$1{\cdot}44^{76}$-B/C	2^{dT}-$1{\cdot}2^{21}$-C	5^{vd}-$1{\cdot}0^{16}$-C	5^{vd}-$1{\cdot}3^{279}$-C	5^{vd}-$2{\cdot}5^{47}$-B	4^{g}-$1{\cdot}4^{25}$-B
	B	8^{d}-$2{\cdot}03^{166}$-B	7^{g}-$2{\cdot}04^{93}$-C	5^{dT}-$1{\cdot}63^{128}$-C	7^{vd}-$1{\cdot}0^{16}$-C	10^{g}-$1{\cdot}7^{268}$-D	6^{vd}-$2{\cdot}7^{41}$-C	9^{d}-$2{\cdot}0^{70}$-C
5	T	7^{d}-$1{\cdot}66^{55}$-C	5^{d}-$1{\cdot}7^{126}$-B			7^{d}-$1{\cdot}8^{210}$-C	$4{\cdot}5^{d}$-$1{\cdot}46^{52}$-B	7^{d}-$1{\cdot}6^{70}$-B
	M	8^{d}-$1{\cdot}44^{45}$-C	4^{vd}-$1{\cdot}47^{107}$-B			7^{d}-$1{\cdot}6^{220}$-C	$5{\cdot}5^{d}$-$1{\cdot}5^{51}$-B/C	7^{d}-$1{\cdot}5^{68}$-C
	B	11^{d}-$2{\cdot}25^{78}$-C	7^{vd}-$1{\cdot}89^{111}$-B			7^{d}-$1{\cdot}7^{246}$-C	$5{\cdot}5^{d}$-$1{\cdot}6^{51}$-B	6^{g}-$1{\cdot}6^{78}$-B
9	T	25^{H}-$1{\cdot}58^{365}$-B	9^{d}-$1{\cdot}8^{33}$-C	28^{dT}-$1{\cdot}56^{70}$-B	26^{d}-$1{\cdot}5^{50}$-B	15^{vd}-$1{\cdot}4^{90}$-C	8^{vd}-$2{\cdot}3^{55}$-A/B	16^{d}-$1{\cdot}7^{85}$-B
	M	7^{vd}-$1{\cdot}3^{166}$-B	9^{vd}-$1{\cdot}93^{45}$-C	3^{dT}-$1{\cdot}53^{19}$-B	7^{vd}-$1{\cdot}7^{87}$-C	8^{vd}-$1{\cdot}5^{79}$-C	$6{\cdot}5^{vd}$-$2{\cdot}1^{62}$-B	8^{vd}-$1{\cdot}8^{45}$-C
	B	9^{vd}-$1{\cdot}53^{218}$-C	9^{g}-$1{\cdot}3^{29}$-C	11^{vdT}-$1{\cdot}36^{61}$-B	6^{d}-$1{\cdot}7^{16}$-B	7^{d}-$1{\cdot}7^{62}$-C	11^{d}-$2{\cdot}2^{62}$-B	5^{d}-$1{\cdot}3^{50}$-C
13	T	8^{d}-$1{\cdot}5^{76}$-C	8^{d}-$1{\cdot}12^{28}$-B	3^{dT}-$1{\cdot}36^{57}$-B		7^{d}-$1{\cdot}4^{278}$-D	10^{vd}-$2{\cdot}84^{50}$-B/C	6^{vd}-$2{\cdot}2^{43}$-C
	M	17^{d}-$1{\cdot}7^{66}$-C	9^{vd}-$1{\cdot}80^{56}$-B	6^{T}-$1{\cdot}27^{45}$-C		9^{d}-$1{\cdot}3^{241}$-C	8^{vd}-$2{\cdot}18^{51}$-B/C	9^{d}-$2{\cdot}1^{35}$-B
	B	17^{g}-$2{\cdot}0^{114}$-C	9^{vd}-$1{\cdot}72^{63}$-B	12^{gT}-$1{\cdot}56^{69}$-C		10^{dT}-$1{\cdot}6^{339}$-B	12^{vd}-$3{\cdot}5^{123}$-B/C	20^{g}-$3{\cdot}4^{69}$-B
17	T	6^{d}-$2{\cdot}04^{21}$-C	7^{vd}-$1{\cdot}63^{93}$-C		7^{vd}-$1{\cdot}0^{35}$-B	8^{d}-$1{\cdot}8^{279}$-C	6^{vd}-$1{\cdot}63^{36}$-B/C	5^{d}-$1{\cdot}8^{27}$-B
	M	9^{vd}-$2{\cdot}16^{109}$-C	6^{vd}-$1{\cdot}71^{126}$-C		7-$1{\cdot}3^{27}$-B	8^{d}-$1{\cdot}5^{210}$-D	$6{\cdot}5^{d}$-$1{\cdot}58^{63}$-C	8^{d}-$1{\cdot}9^{28}$-C
	B	10^{vd}-$2{\cdot}46^{173}$-C	6^{d}-$1{\cdot}94^{126}$-C		9^{vd}-$0{\cdot}8^{21}$-B	8^{d}-$1{\cdot}9^{288}$-D	$9{\cdot}5^{g}$-$2{\cdot}07^{113}$-C	8^{d}-$2{\cdot}2^{24}$-C
21	T	8^{T}-$1{\cdot}3^{109}$-B	7^{vd}-$1{\cdot}24^{37}$-C	7^{T}-$1{\cdot}12^{44}$-B	7-$1{\cdot}7^{24}$-B	7-$1{\cdot}3^{56}$-C	7^{vd}-$1{\cdot}94^{45}$-C	5-$1{\cdot}3^{32}$-B
	M	4^{T}-$1{\cdot}3^{109}$-B	12^{g}-$1{\cdot}4^{31}$-C	2^{T}-$1{\cdot}12^{16}$-B	6^{vd}-$1{\cdot}4^{16}$-C	2-$0{\cdot}9^{68}$-C	$6{\cdot}5^{vd}$-$1{\cdot}97^{51}$-C	8^{vd}-$1{\cdot}4^{39}$-C
	B	7^{d}-$1{\cdot}5^{151}$-C	8^{vd}-$1{\cdot}72^{33}$-C	6^{d}-$1{\cdot}41^{58}$-B	7^{d}-$1{\cdot}6^{49}$-B	5-$1{\cdot}3^{219}$-C	9^{vd}-$2{\cdot}55^{46}$-B	8^{vd}-$1{\cdot}7^{45}$-C
25	T	6^{vd}-$1{\cdot}67^{56}$-C	9^{g}-$1{\cdot}35^{34}$-B	3^{T}-$1{\cdot}27^{56}$-B		3-$1{\cdot}1^{109}$-B	6^{vd}-$2{\cdot}27^{41}$-B	5-$2{\cdot}3^{30}$-B
	M	9^{vd}-$1{\cdot}46^{52}$-C	7^{vd}-$1{\cdot}72^{56}$-B	5^{T}-$1{\cdot}3^{49}$-B		4^{d}-$1{\cdot}3^{164}$-C	5^{vd}-$2{\cdot}33^{50}$-B	6^{d}-$2{\cdot}2^{24}$-B
	B	11^{g}-$2{\cdot}0^{147}$-C	9^{g}-$1{\cdot}5^{33}$-B	9^{d}-$1{\cdot}83^{107}$-B		8^{d}-$1{\cdot}7^{168}$-C	9^{vd}-$2{\cdot}5^{42}$-B	10^{dH}-$3{\cdot}1^{63}$-B



1 *Only inclusions intercepted by the intersection of the cross-wires, such as A, B, and C are counted*

were mostly sulphides and silicates with a small proportion of a duplex variety. As an additional aid to differentiating between sulphides and silicates the Whiteley technique for silvering sulphides was employed.* The results obtained are shown in Table V from which it can be seen that the observers are unable to agree on the relative proportions of the different types of inclusions, and a lower degree of reproducibility is also obtained for total inclusions. It would appear that the extra personal judgment required to differentiate between different types of inclusions not only exposes this task to personal errors, but also lowers the efficiency of the basic task of counting inclusions.

A relatively simple counting method such as that described above is obviously of considerable use where the total inclusion count, regardless of the proportions of different types of inclusions present, is required. On the other hand it is clear that asking an observer to differentiate between the various types of inclusion present renders the method no better than the three originally examined.

EFFECT OF MECHANICAL REDUCTION

Inclusion counts are usually performed on semi-finished material, such as billet, or occasionally at the finished stage. The effect of mechanical working on the morphology of inclusions is complex, however, and dependent upon several factors. In general, as the material is progressively reduced from the ingot, inclusions will tend to be drawn out into thin threads aligned in the direction of working, or to be broken up and dispersed. Whatever the precise effect, the results of inclusion counts based on examination with a microscope may be expected to be affected by the degree of reduction from the ingot. Whenever comparable results are required, therefore, a specified degree of reduction should be decided. Although a fixed specimen size is specified in many instances (e.g. $1\frac{3}{8}$-in. dia. bar for the Fox count) the degree of reduction is not fixed, because this will depend on the original ingot cross-section. An experiment was performed to investigate the effect of mechanical reduction on the total inclusion count as determined by the lineal-traverse method.

* J. W. Whiteley: *JISI*, 1948, **160**, 365–367.

TABLE IV Results of lineal-traverse counts

Specimen	Operator 1	2	3	4	5	6	7	8	9	10
A	4	5	5	6	5	3	4	6	4	5
B	4	2	3	4	4	5	6	5	3	5
C	5	6	11	7	5	6	7	6	6	7
D	9	7	10	10	7	9	9	9	10	8
E	8	8	9	8	8	8	10	10	7	8
F	20	17	17	60	19	20	24	25	21	21
G	57	45	72	58	50	51	46	46	40	49

Inclusions/cm correct to nearest whole number
Total traverse length, 10 cm
Magnification, ×90

TABLE V Results of lineal-traverse counts

Specimen	Type of inclusion	Operators 1	2	3	4	5	6	7	8	9	10
H	Sulphide	2	2	4	5	2	4	3	4	4	2
	Silicate	4	5	6	10	8	5	7	6	8	10
	Duplex	1	0	0	2	2	1	1	0	1	1
	Total	7	7	10	17	12	10	11	10	13	13
K	Sulphide	3	2	6	2	4	3	3	4	4	2
	Silicate	4	4	6	4	9	2	5	6	4	7
	Duplex	3	0	1	2	3	1	1	1	1	1
	Total	10	6	13	8	16	6	9	11	9	10

Inclusions/cm, corrected to nearest whole numbers.
Total traverse length, 20 cm.
Magnification, ×90
Whiteley's test for sulphides applied

Experiment

Five casts of steel were examined, the qualities being shown in Table VI. The ingots were of two sizes, 10-in. and 20-in. square cross-section. They were initially reduced by rolling to square-sectioned billets which were then step-forged to provide specimens with smaller cross-sections. Lineal-traverse inclusion counts were performed by one observer on longitudinal sections in the manner described earlier.

Results

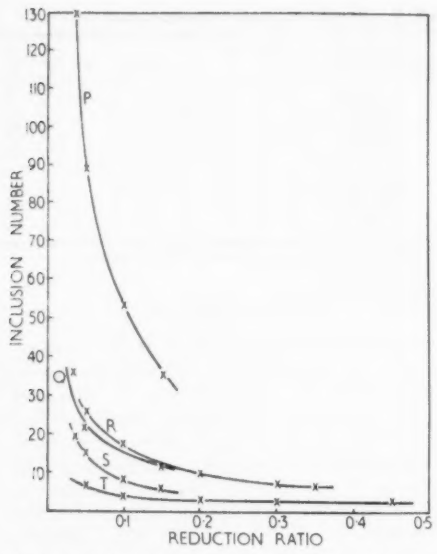
A convenient term for defining the degree of reduction was the ratio (width of cross-section of specimen)/(width of original ingot cross-section) which is henceforth referred to as the reduction ratio. If the inclusion count determinations are plotted against the reduction ratios a series of curves (Fig.2) is obtained which indicates that for some steels the inclusion count varies considerably with the reduction ratio, while for others a large change in reduction ratio produces little effect upon the inclusion count recorded.

It is of interest to attempt a simple analysis of the effect of mechanical reduction on the results of the lineal-traverse counting method.

Figure 3 represents the side projection of a square-sectioned ingot before and after reduction, and inclusions both on the surface and within the material are shown. The inclusion counts are to be made along a

TABLE VI Steels used in investigating the effect of reduction

Cast	Quality	Mean ingot section	Predominant inclusions
P	Leaded free-cutting	20 in²	Sulphides
Q	Basic open-hearth 0·3% carbon	20 in²	Sulphides Silicates
R	Basic open-hearth silicon manganese spring steel	10 in²	Sulphides Silicates
S	Basic electric plain carbon	20 in²	Small sulphides
T	Basic electric En 352 with titanium addition	10 in²	Small sulphides and titanium nitrides



2 *Inclusion numbers plotted against reduction ratios*

line perpendicular to the plane of the paper. The chance of hitting an inclusion before reduction is $\frac{a_1}{Bd}$ where a_1 is the area of an average inclusion in the plane of the paper. If a total of n inclusions are present, on one traverse an average of $\frac{na_1}{Bd}$ will be counted, and the inclusion number will be C, where

$$C_1=\frac{na_1}{B^2d} \text{ inclusions per unit length of traverse.}$$

Similarly, after reduction, the inclusion number will be

$$C_2=\frac{na_2}{b^2D} \text{ inclusions per unit length of traverse.}$$

Therefore, $C_2=\frac{na_2}{b^2D}\cdot\frac{B^2d}{na_1}\cdot C_1$

and since the volume of the material is constant,

$$B^2d=b^2D$$

whence $C_2=\frac{a_2}{a_1}\cdot C_1$.

If the inclusions are hard and do not deform,

$$a_1=a_2$$

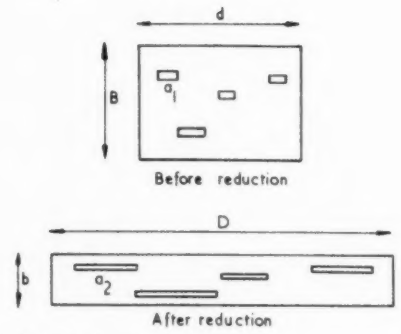
and $C_2=C_1$.

Thus for hard inclusions the inclusion number is unaltered by reduction. But if the inclusions are plastic and deform at the same rate as the steel,

$$\frac{a_2}{a_1}=\frac{bD}{Bd}=\frac{B}{b}=\frac{1}{R}$$ where R is the reduction ratio.

Therefore, $C_2=\frac{C_1}{R}$.

Thus for plastic inclusions the inclusion number varies inversely as the reduction ratio, and a plot of inclusion number against reduction ratio gives a hyperbolic curve.



3 *The effect of reduction*

The experimental curves shown in Fig.2 are approaching this form, especially in the case of cast P. This material contained mostly sulphide inclusions which are plastic at rolling temperatures. Cast T, on the other hand, which contained hard titanium nitride inclusions, had a nearly constant inclusion number.

CONCLUSIONS AND SUMMARY

Three widely used methods of inclusion counting in steels, the Fox, SAE, and Jernkontoret methods have been employed by a group of microscopists working in separate laboratories to determine the inclusion contents of a series of steels. It may be concluded from the results obtained that the three counting methods are incapable of yielding reproducible results. The reasons for this are mental fatigue, associated with performing an uninteresting and repetitive task, and the high degree of personal judgment required in assessing the inclusion content of a steel by these methods.

A new inclusion-counting technique, designated the lineal-traverse count, has been described. This method is simple and requires little personal judgment on the part of the operator. An experiment has shown that highly reproducible inclusion counts can be obtained when the total inclusion content of a steel is determined. If, however, the observer employing the technique is required to count the various types of inclusion separately, i.e. to exercise a high degree of judgment, then the reproducibility is again poor.

The reduction in area applied to the steel has been shown to have, in certain cases, a profound effect upon its total inclusion content as determined by the lineal-traverse count. Mathematical analysis has shown that the precise effect of variations in reduction in area is related to the nature of the inclusion at rolling temperature, whether it is hard, such as titanium nitride, or plastic, as is the case with sulphides. When the inclusions are hard the variation of inclusion count with the reduction in area is small, but when the inclusions are soft the inclusion count varies inversely with the reduction ratio. The experimental results obtained support the mathematical analysis.

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Effect of creep deformation at 700°C on the transformation of molybdenum carbides in a ferritic steel

K. A. Ridal and A. G. Quarrell

UNTIL RECENTLY few systematic studies of structural changes in alloys during creep deformation had been made, but extensive investigations[1,2] had shown that the overall effect of prior plastic deformation is to increase the rate of precipitation from supersaturated solid solutions, and it has been inferred that creep deformation will similarly accelerate precipitation processes.

Recently Nileshwar and Quarrell[3,4] have studied the effect of creep deformation upon the transformations of chromium and molybdenum carbides, which occur during the fourth stage of tempering in alloy steels. Their results show that at 600°C creep strain retards the $Cr_7C_3 \rightarrow Cr_{23}C_6$ transformation in a 0·2%C–9%Cr steel. Creep at 600°C also appears to retard the $Mo_2C \rightarrow M_6C$ transformation in a 0·185%C–3·4%Mo steel. The retardation of the chromium carbide reaction has since been confirmed by an independent investigation,[5] which has also shown that creep retards the $Fe_3C \rightarrow Cr_7C_3$ transformation in the same steel. Underwood and Manning[6] have reported that the dissolution of $CuAl_2$ in an over-aged Al–3%Cu alloy was retarded by creep, and this has been verified by Garstone and Nileshwar.[7]

These results are contrary to expectations and as yet have not been satisfactorily explained. A tentative theory advanced by Bilby and Pickering[8] does not appear to be consistent with all the experimental findings.

The present investigation is a continuation of Nileshwar and Quarrell's work.[4] Following their detailed study of the effect of creep strain upon the $Cr_7C_3 \rightarrow Cr_{23}C_6$ reaction it was felt that a similar detailed investigation of the $Mo_2C \rightarrow M_6C$ reaction should be undertaken to establish the effect of varying strain rates. A molybdenum steel intended to be similar to that used by Nileshwar and Quarrell[4] was prepared. Owing to a slight difference in composition the rate of tempering was much slower than in the earlier steel. Most of the experimental work was therefore undertaken at 700°C to reduce the tempering times to reasonable values.

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SYNOPSIS

The effect of creep deformation upon the $Mo_2C \rightarrow M_6C$ *transformation has been studied in a 0·24%C–3·4%Mo steel during tempering at 700°C. Changes were followed by chemical and X-ray analysis of carbides electrolytically extracted from the steel, by hardness measurements, and by electron microscopy. Strain accelerated the reaction, the degree of acceleration increasing with higher rates of straining.* 1808

EXPERIMENTAL

Material

The steel investigated had the following chemical composition, wt-%:

0·24%C	0·07%Ni
0·16%Si	0·02%Cr
0·17%Mn	3·43%Mo
0·027%S	0·022%Al
0·033%P	5 ppm acid soluble } B 5 ppm acid insoluble }

It was made in an induction furnace by melting 110 lb of Low Moor iron and adding ferro-molybdenum and white iron to give the desired analysis. The melt was deoxidized with silicon, manganese, and aluminium metals, and cast into a 4-in. square billet. The billet was forged and rolled down to $\frac{3}{4}$-in. dia. bar.

Heat-treatment

(i) *Plain tempered specimens*

Cylinders of the steel 5 in. long by $\frac{5}{8}$ in. dia. were homogenized for 4 h at 1200±10°C in an argon atmosphere. To minimize the possibility of δ-ferrite formation the steel was cooled to 1150°C for $\frac{1}{2}$ h before quenching into brine at room temperature; (*see* Fe–Mo–C phase diagrams).[9] Specimens about $\frac{3}{4}$ in. long were slit from the hardened material on a high-speed carborundum wheel with coolant and were tempered in salt baths at 600, 650, and 700±3°C for times ranging from 1–1000 h.

(ii) *Creep tempered specimens*

Creep specimens of 2 in. gauge length and 0·26 in. dia. and of $2\frac{1}{2}$ in. gauge length and 0·30 in. dia. were machined for constant strain and constant

load tests respectively. They were homogenized and hardened in the same manner as the cylinders used for the tempering experiments.

In preliminary experiments a few specimens tempered more rapidly than the rest. This was found to occur when the as-quenched hardness was low (440–470 DPN), and accordingly only those specimens were used that had an as-quenched hardness of 480–500 DPN.

The creep specimens were machined with small control sections at each end. One of these, removed after quenching, was used to check as-quenched hardness; the other, removed after the creep test, provided a comparison with the tempered hardness.

As is often the case with highly alloyed steels, it was difficult to decide with certainty whether the as-quenched structure was bainitic or martensitic. However, this is unimportant as the tempering behaviour of lower bainite and martensite will be similar at temperatures above 500°C. The general appearance of the microstructure of the quenched steel was very similar to the structure which is usually termed bainite. The name bainite will therefore be used in further reference to the as-quenched structure.

The majority of creep experiments were conducted at constant strain rates in a modified Hounsfield tensometer, while the lowest creep rate was obtained by a fixed load test in a modified Buckton tensile testing machine.[4,10] The test temperature was 700±3°C over the entire gauge length for all specimens. Creep specimens were coated with special high temperature aluminium paint as this has been found to reduce surface oxidation. On completion of the tempering and creep-tempering, specimens were water quenched.

(iii) *Metallurgical examination*

Before examination, about 0·040 in. was machined from the surfaces of all specimens to remove any decarburized material.

Carbides were electrolytically extracted from the tempered specimens in a neutral citrate cell, similar in principle to that described by Smith.[11] A porous pot separated the anolyte from the catholyte, and the current density was about 0·04 amps/cm^2. The carbide residue was separated by centrifuging, and washed successively with 0·5% sodium thiocyanate, absolute alcohol, and ether before drying at room temperature. A yield of about 30 mg of carbide was obtained from the dissolution of 1 g of steel; 5–10 m of the extracted carbide was analysed for molybdenum and iron, using a semi-microchemical method.[12] The carbide extract was also subjected to X-ray analysis, using a low-angle focusing camera[13] and CoKα radiation rendered monochromatic by a bent quartz crystal. The diffraction pattern was recorded on Ilford B X-ray film and the relative proportions of the carbides present were determined by measuring the integrated intensities of the appropriate diffraction lines on a micro-densitometer.

Sections of the tempered specimens and of the gauge lengths of the creep specimens were used for hardness determinations and for both light and electron microscopic examination.

RESULTS

Examination of the preliminary specimens tempered at 600° and 650°C for times up to 200 h revealed no carbide other than Mo_2C; this carbide was first precipitated in the form of a Widmanstätten structure of fine needles. On further tempering the carbide needles increased in size, and the carbides at prior austenite and bainite boundaries spheroidized and grew at the expense of the surrounding needles. Diffuse X-ray diffraction patterns corresponding to the Mo_2C structure,[14] were obtained from carbides extracted from a specimen tempered for 4 h at 600°C. The diffractions became progressively sharper with increased time and temperature of tempering. This was accompanied by an increase in the particle size and the number of spheroidal carbides, and a decrease in the iron content of the carbide extract.

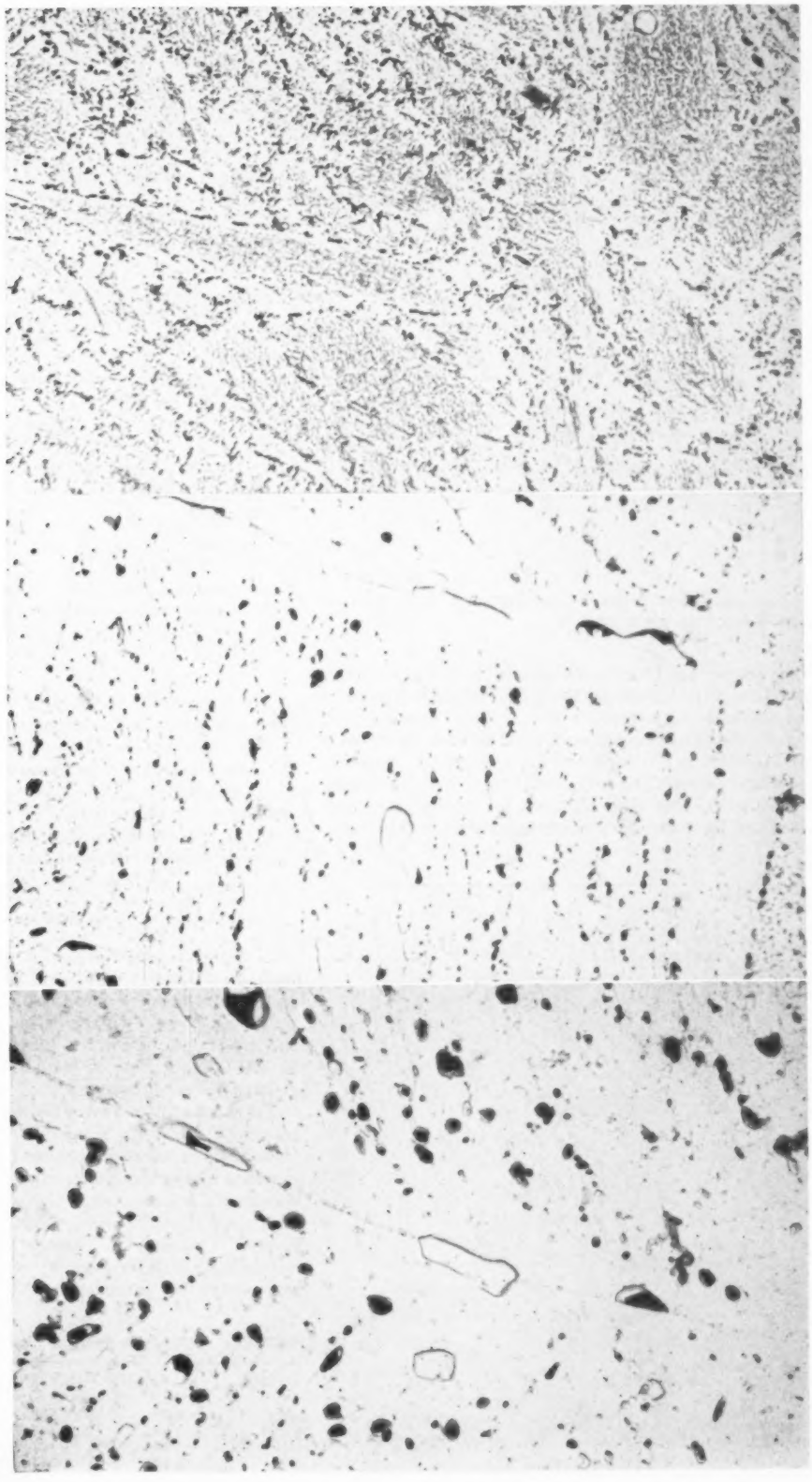
Similar morphological changes were observed for specimens tempered at 700°C, but the time for any particular microstructure to be attained was greatly reduced, and this temperature was suitable for the creep-tempering investigation.

The electron micrographs in Fig.1 give a general impression of the progress of tempering. After 48 h tempering at 700°C the first trace of η-carbide, M_6C,[14] was detected by X-ray analysis. The quantity of M_6C gradually increased with time, until about 35% of the Mo_2C had transformed to M_6C. No further increase in the amount of M_6C was observed on increasing the tempering time to 960 h although the size of the carbide particles continued to increase. The onset of transformation was accompanied by an increase in the iron content of the carbide extract, as might be expected from the rough formula for η-carbide, i.e. Fe_4Mo_2C. It is noteworthy that in this steel Mo_2C was observed both as acicular and spheroidal particles (Fig.1*a*), whereas Nileshwar and Quarrell[4] associated the appearance of spheroidal carbide particles with the onset of the Mo_2C to M_6C transformation and regarded the spheroidal particles as M_6C. The X-ray results were checked by electron diffraction on the carbon extraction replicas.

Constant strain-rate tests were performed at strain rates of 0·171, 0·095, 0·053, and 0·027%/h. During the period of a test the load increased linearly with time, gradually became constant, and finally decreased, slowly at first and then sharply just before fracture. The latter effect was associated with the formation of intergranular cracks and necking of the specimen. Typical times to fracture were 31 h at 0·171%/h, 48 h at 0·095%/h, and 80 h at 0·053%/h, but specimens tested under similar conditions showed variations comparable with those usually experienced with creep rupture tests.

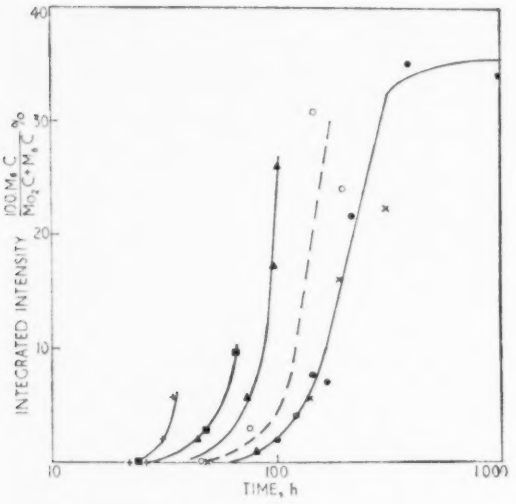
Constant load tests at 1 ton/in^2 were performed for times ranging from 48 – 310 h. The strain rate under such conditions was not constant, but with the relatively small load used the steady creep condition was maintained throughout most of the test. Again the behaviour of individual specimens was not identical, but the deviations were within the limits of the experiment and of a magnitude which might be anticipated for such a structure-sensitive property as creep. The minimum and average strain rates were 0·0025–0·0030%/h and 0·004%/h respectively.

The collected results for the tempered and creep-tempered specimens are presented in Figs.2–4. Figure 2 is a summary of the X-ray data; the integrated intensity/ratio $100M_6C(Mo_2C+M_6C)\%$, which is proportional

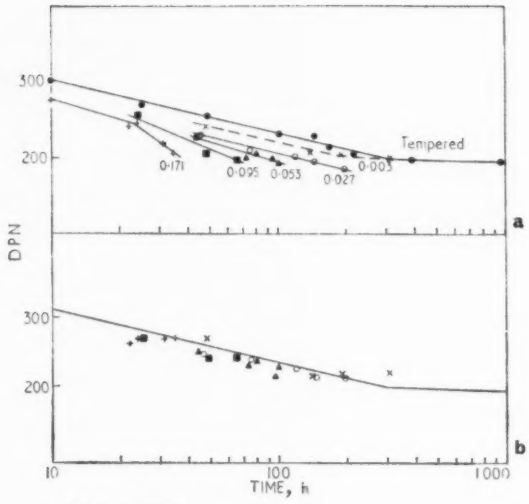


(a) 24 h
(b) 216 h
(c) 960 h

1 *Electron micrographs of 0·24%C–3·43% Mo steel tempered at 700°C. Carbon extraction replicas* ×7 500



2 *X-ray analysis of carbides extracted from plain-tempered and creep-tempered specimens*



4 (a) *Hardness of plain-tempered and creep-tempered specimens*
(b) *Hardness of unstrained control samples from end of creep specimens, compared with the results for plain-tempered specimens*

to the percentage transformation, is plotted against the logarithm of the tempering time. For each X-ray pattern four diffraction line profiles (*see* Table I) were plotted from the densitometer record, and the area under each profile, which is a measure of the integrated intensity, was determined. The 101 Mo_2C and 333 M_6C lines proved to be the most suitable for comparison and were used for computing the intensity ratio. The ratio of the integrated intensity of the two Mo_2C lines was used as a check on the experimental accuracy.

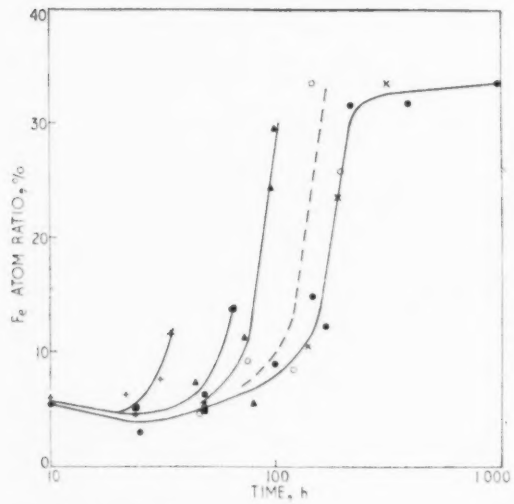
The information obtainable directly from the chemical analysis of the carbide extracts is limited owing to contamination by non-metallic inclusions from the steel and moisture from the atmosphere. A clearer indication of the actual carbide composition is obtained by expressing the results as an atomic ratio, viz.:

$$\text{Iron atom ratio} = 100\ \text{Fe}/(\text{Fe}+\text{Mo})\%,$$

$$\text{where Fe} = \frac{\text{wt-\% Fe}}{\text{atomic wt Fe}}, \text{ and Mo} = \frac{\text{wt-\% Mo}}{\text{atomic wt Mo}}.$$

The change in iron atom ratio with time, on tempering with and without strain, is plotted in Fig.3. These results are directly comparable with the X-ray analyses (Fig.2); both clearly show that strain *accelerates* the molybdenum carbide transformation in this steel at 700°C, and that the higher the strain rate ($\dot{\epsilon}$) the greater the acceleration.

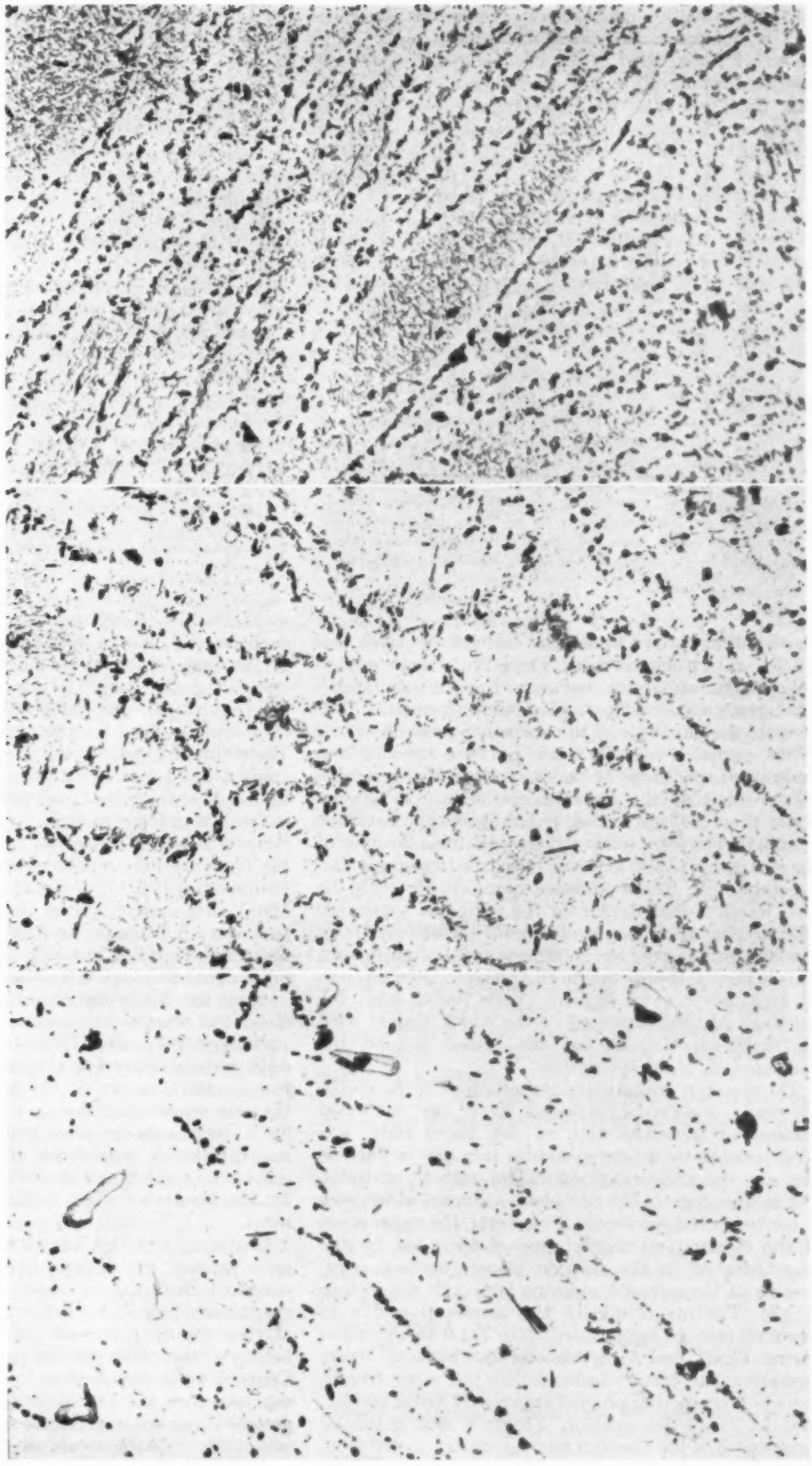
These conclusions are substantiated by the hardness results (Fig.4*a*). The strained specimens were all softer than unstrained specimens, and the degree of softening increased with the strain rate. Results obtained from specimens strained at 0·171%/h for times less than 10 h show that the change in slope indicated in Fig.4*a* is real. This sudden change is associated with the appearance of intergranular cracks in the specimens, and serves to emphasize that the hardness results



3 *Iron–atom ratios of extracted carbides*

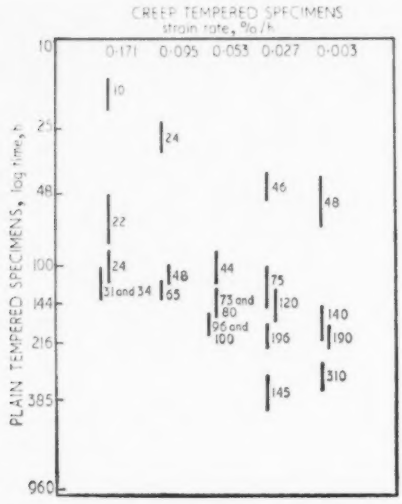
TABLE I Diffraction lines used for intensity measurements

Carbide	d-value kX	Diffraction	Intensity
Mo_2C	2·36	002	Medium weak
Mo_2C	2·27	101	Strong
M_6C	2·25	422	Strong
M_6C	2·12	333, 511	Very strong

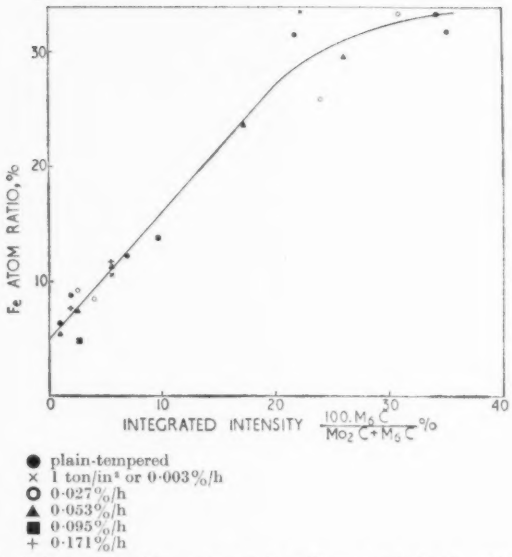


(a) 0·171%/h for 34 h at 700°C
(b) 0·027%/h for 75 h at 700°C
(c) 0·027%/h for 146 h at 700°C

5 *Typical electron micrographs of creep-tempered specimens of 0·24%C–3·43%Mo steel. Carbon extraction replicas* ×7500



6 *Comparison of electron micrographs. Specimens creep-tempered for times indicated by numbers, possessed microstructures which were comparable with specimens plain-tempered for the ranges of time represented by the vertical lines. See text for details*



7 *Relationship of iron–atom ratio to X-ray analysis of carbide extracts*

provide information about the state of the steel as a whole, matrix and carbides. Thus, while there was no appreciable difference between the carbide transformations without stress and at 1ton/in², a small difference in the hardness of the specimens was observed. When comparisons were made between strained and unstrained specimens at the same stage of the carbide transformation, the strained specimen was always softer than the unstrained. Fig.4*b* shows the hardness results for the plain tempered samples from the ends of the specimens tested in creep, both constant strain and constant load. These compare quite closely with the line, which is that drawn for the tempered specimens (Fig.4*a*), but there is a tendency for the samples from the constant strain-rate specimens to be slightly soft. This is very probably due to their having been tempered at a temperature slightly above 700°C, since the constant temperature zone of the small furnace used for these experiments did not extend beyond the gauge length of the specimens.

The electron microscopic examination of the creep-tempered specimens revealed that the increased amount of transformation at any given time, was accompanied by a corresponding increase in particle size and the number of spheroidal carbide particles. The morphology of the carbides was identical to those in the tempered specimens. In general, the appearance of the electron micrograph was determined by the stage reached in the carbide transformation, irrespective of the actual tempering time and strain rate (Fig.5). The magnitude of the acceleration due to straining may be appreciated from Fig.6 and by comparing Figs.1 and 5. Specimens in which no transformation has occurred also follow the same trends, the whole tempering process apparently being accelerated by creep deformation. Figure 6 is a graphical comparison of the electron micrographs obtained from strained and plain tempered specimens. The times for which specimens were tempered at 700°C are indicated on the vertical log (time) scale. The microstructure of each creep-tempered specimen was assessed in terms of the time which would have been required for an equivalent structure to be attained by plain tempering. This equivalent tempering time is plotted on the same time scale as used for the plain tempered specimens. The results for each strain rate are plotted in separate columns and the actual time of the creep test is indicated at the side of each plot. Precise assessment of individual microstructures was difficult, so a time range is indicated by a short vertical line. For example, the vertical line representing the specimen creep-tempered at 0·171%/h for 24 h, is drawn from 85 to 120 h, indicating that the observed microstructure is judged to be similar to that of a specimen plain-tempered for 100 h, but with a possible error of assessment of about 15 to 20 h either way.

From the X-ray and chemical results (Figs.2 and 3) it is clear that a few specimens do not fall on the smooth curves drawn. These deviations are not reflected in the hardness results (Fig.4*a*), probably owing to the less sensitive nature of the hardness test. However, they are apparent in the electron micrographs (Fig.6). Such deviations are most probably caused by small uncontrollable differences in composition of the individual specimens due to segregation in the steel, or by the inevitable slight difference in the heat-treatment.

Comparison of Figs.2 and 3 shows that any apparent error in, say, the X-ray analysis, is reflected in the chemical analysis. If these results are compared graphically (Fig.7) very close agreement is obtained, as they fall on a smooth curve. Also no distinction between the different strain rates is noticeable. Coupled with the electron microscope evidence, this suggests that the carbide reaction in this steel progresses along the same reaction path regardless of the strain rate, and the accompanying acceleration.

Although the experimental accuracy makes the drawing of the curves in Fig.2 somewhat schematic the

general picture is one of acceleration, the degree of acceleration increasing with increased strain rate.

DISCUSSION

The results show that in the 0·24%C–3·43%Mo steel investigated, the effect of creep at 700°C is to accelerate the $Mo_2C \rightarrow M_6C$ reaction. This behaviour may be contrasted with the earlier observations that creep deformation retarded the $Cr_7C_3 \rightarrow Cr_{23}C_6$ and $Mo_2C \rightarrow M_6C$ transformations in steel at 600°C,[4,5] and also retarded the dissolution of $CuAl_2$ in a Al-3%Cu alloy.[6,7]

A possible explanation for this retardation has been advanced by Bilby and Pickering[8]; their theory also predicts acceleration under some circumstances. Briefly, it is supposed that during creep the structure contains a supersaturation of vacancies produced by climbing dislocations. If then a precipitation reaction results in a net volume contraction, the hole which would be formed will be dispersed by the emission of vacancies. This process becomes more difficult as the supersaturation of vacancies in the surrounding matrix increases, and it is suggested that the reaction will therefore be retarded under creep conditions. Conversely, if the reaction is accompanied by a net expansion it will be accelerated by creep strain. On the basis of calculated volume changes Bilby and Pickering predicted retardation for the $Fe_3C \rightarrow Cr_7C_3 \rightarrow Cr_{23}C_6$ and $Mo_2C \rightarrow M_6C$ reactions, provided the rate of transformation is controlled by the dissolution of the less stable carbide.

To understand the carbide reaction fully a detailed knowledge of the transformation mechanism is required. However, it is very difficult to ascertain whether a reaction occurs *in situ* or by re-nucleation and growth. The mechanism by which a given transformation occurs may well vary with the composition of the steel investigated, and possibly with the tempering temperature.

In the present investigation the spheroidal particles of Mo_2C had grown at the expense of the acicular particles before the transformation occurred. No new precipitate was observed at the start of the transformation and no increase in hardness was noted. The diffraction patterns of Mo_2C obtained from the carbide extracts all showed line broadening due to the small size of some of the carbide particles, although this effect became less pronounced with carbides extracted from specimens in an advanced stage of tempering. However, the M_6C diffractions were sharply defined, and the line width was of the same order as the instrumental broadening, even when only a very limited amount of transformation had occurred. On this evidence it would appear that the large spheroidal particles of Mo_2C transformed *in situ* to M_6C.

It is believed that under the present experimental conditions transformation proceeds as follows. The spheroidized Mo_2C particles, which initially contain an appreciable quantity of iron, gradually become enriched with molybdenum, and eventually reach a composition at which they are able to transform *in situ* to M_6C, by absorbing metal atoms from the surrounding matrix. The additional molybdenum atoms for the enrichment of the Mo_2C, which is an essential preliminary to the transformation, are supplied by diffusion from the matrix.

This transformation mechanism is analogous to that envisaged by Shaw and Quarrell[15] for the $Cr_7C_3 \rightarrow Cr_{23}C_6$ transformation in low-carbon chromium steels. They found that at least 80% of the metal atoms in Cr_7C_3 had to be chromium before the transformation to $Cr_{23}C_6$ occurred. Presumably this provided the minimum concentration of chromium atoms necessary to stabilize the $Cr_{23}C_6$ structure resulting from the transformation.

In the present investigation spheroidization and enrichment of the Mo_2C occurred together. It might, therefore, be thought that the enrichment was a result of the spheroidization, but, if the carbide particles are initially of similar composition, dissolution followed by diffusion of the resulting atoms to the growing particles cannot cause enrichment. Indeed, there will at first be a reduction in the molybdenum concentration in the Mo_2C, owing to the slow rate of diffusion of the molybdenum atoms. Even in the absence of spheroidization, enrichment of the Mo_2C will occur, because of the low initial concentration in the carbide and the relatively high concentration in the matrix.

On this picture of the transformation process, the rate at which conditions conducive to the formation of M_6C are established is determined by the rate at which molybdenum atoms can diffuse through the matrix. Clearly it is important to consider the effect of strain on this diffusion rate.

Several investigators[16–18] have shown, by direct radioactive tracer techniques, that creep deformation increases the coefficient of self-diffusion of a metal. The increased equilibrium concentration of vacancies and dislocations present in a metal under creep conditions is thought to be responsible for this enhanced diffusion. It has been verified that for α-Fe under uniaxial compression[16] and for Ag in torsion and compression[17, 18] the increase in the coefficient of self-diffusion is proportional to the strain rate.

If t is the time to a given stage in the tempering reaction, then

$$D \propto 1/t \qquad (1)$$

It is well known that

$$D = D_0 \exp(-Q/RT) \qquad (2)$$

where D_0 is a constant, Q is the activation energy of diffusion, R is the gas constant, and T is the absolute temperature. For the process to be accelerated by creep, either D_0 must increase or Q decrease with increased strain rate.

Buffington and Cohen[16] found for the self-diffusion of iron in α-Fe a strain dependency of the form*

$$D_\epsilon/D = 1 + k\dot{\epsilon} \qquad (3)$$

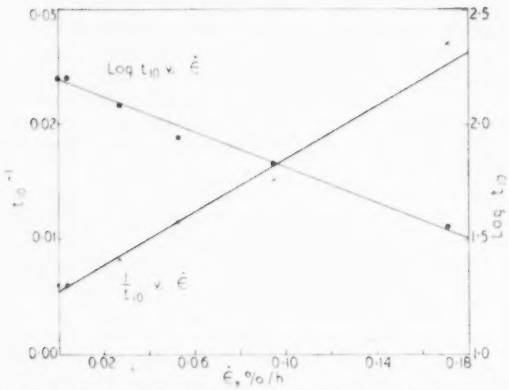
where D_ϵ and D are the diffusion coefficients with and without strain respectively, k is a constant, and $\dot{\epsilon}$ is the strain rate.

If t_ϵ and t are the times to a given stage in the tempering processes, equations (1) and (3) would predict a strain rate dependency of the form

$$1/t_\epsilon = 1/t + K_1\dot{\epsilon} \qquad (4)$$

where K_1 is a constant.

* Several experimental difficulties in the measurement of self-diffusivity during compressive creep were not recognized in the original paper. Ujiiye *et al.*[19] have pointed out these difficulties and the overall result has been a reduction in the magnitude of the acceleration.



8 *Strain rate* v. *logarithm and inverse of time to constant amount of transformation*

Alternatively, if D_0 is unaffected and the activation energy Q is linearly dependent upon the strain rate, an equation of the form

$$\log t_\epsilon = \log t + K_2\dot{\epsilon} \quad \ldots\ldots(5)$$

would result.

Figure 8 shows that reasonably good straight lines are obtained when $1/t_{10}$ and $\log t_{10}$ are plotted against $\dot{\epsilon}$, where t_{10} is the time in hours for the integrated intensity 100 $M_6C/(Mo_2C+M_6C)\%$ to equal 10%. The result for $\dot{\epsilon}=0{\cdot}171\%/h$ is the least accurate and was obtained by extrapolation. It is not surprising that both functions give straight line relationships because the curve $\log x$ *v.* $1/x$ has only a gentle curvature $\left(\frac{d^2 \log x}{d\,(1/x)^2}\right)$ over the range $x = 30 - 160$. The inverse time relationship agrees with the experimental data for self-diffusion in pure metals, which is outlined above.

The acceleration of the $Mo_2C \rightarrow M_6C$ transformation observed in the present investigation is consistent with the enhancement of self-diffusion by creep-strain, which has been reported for pure metals.[16–18] However, the results must also be considered in relation to Nileshwar and Quarrell's observation,[4] that creep deformation retarded the same transformation in a molybdenum steel of only slightly different composition at 600°C. Unfortunately, this earlier investigation was not very extensive and it may be considered that there is insufficient experimental evidence for the retardation of the $Mo_2C \rightarrow M_6C$ reaction. However, the same workers showed beyond doubt that the $Cr_7C_3 \rightarrow Cr_{23}C_6$ reaction can be retarded by creep deformation at 600°C.[4] The chromium and molybdenum carbide transformations are similar in that they are both believed to be controlled by the rate of diffusion of the alloying element. Why, then, should creep deformation sometimes cause an acceleration and sometimes a retardation?

For all the steels under consideration, a comparable number of creep-induced lattice defects must have been present in the ferrite matrix. As already explained, it is usually held that the increase in lattice vacancies occurring during creep will speed up the diffusion process, but a second effect may be envisaged that would impede the movement of solute atoms. It may be possible for diffusion to be hindered by temporary association of the solute atoms with the stress fields of the dislocations, as suggested by Garstone and Nileshwar,[7] or alternatively by interaction with groups or clusters of vacancies. However, it would be expected that above some critical temperature the diffusing atoms would have sufficient thermal energy to escape from such 'diffusion traps'. The effect of creep upon the diffusion process would then be governed by the balance of these opposing processes, which in turn would depend upon the test temperature.

If the test temperature is so high that solute atoms are not held by the 'diffusion traps' the accelerating effect caused by the additional creep-induced vacancies will predominate. Below the hypothetical critical temperature the 'diffusion traps' will offset this effect to a progressively greater extent as the temperature is lowered, and at a sufficiently low temperature the diffusion process may be retarded.

Clearly, the above approach would predict that creep deformation would retard a diffusion-controlled process at relatively low temperatures, and accelerate it at relatively high temperatures. This agrees qualitatively with the fact that Nileshwar and Quarrell[4] observed retardation of the $Cr_7C_3 \rightarrow Cr_{23}C_6$ and $Mo_2C \rightarrow M_6C$ transformations at 600°C, while in the present investigation the $Mo_2C \rightarrow M_6C$ transformation was accelerated at 700°C.

Further experimental work is now in progress. An attempt will be made to determine the effect of creep deformation on the $Mo_2C \rightarrow M_6C$ transformation over a range of temperatures, in order to test the above hypothesis.

ACKNOWLEDGMENTS

Our grateful thanks are due to English Steel Corporation Ltd, who rolled the steel and provided financial support for one of us (K.A.R.). Thanks are also due to numerous colleagues for helpful discussions, particularly Dr B. A. Bilby.

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Discussion at the Autumn Meeting 1959

The Autumn General Meeting of The Iron and Steel Institute was held on Wednesday and Thursday, 2–3 December 1959 at the Great Hall, Caxton Hall, Caxton Street, London SW1. The President (Mr W. Barr, O.B.E.) was in the Chair. Technical sessions A and B were held at Caxton Hall, while technical sessions C–F were held at the Hoare Memorial Hall, Church House, Great Smith Street, London SW1. Discussions at some of the technical sessions are given below; others will be published in the Journal *later this year.*

Discussion on steels for forging

This discussion was based on the paper

'Steels for forging', by *R. J. Brown*, F.I.M., A.M.I.MECH.E. (The Austin Motor Co. Ltd). The paper appears on pp.278–286 of this issue. Mr Brown presented his paper.

Mr **J. F. Sewell** (Samuel Fox and Co. Ltd): Mr Brown has performed a most useful service in presenting, in concise form, the major difficulties experienced by the user metallurgist in acquiring and fabricating steel. By clearly defining the target he offers guidance to the steelmaker in his efforts to supply a satisfactory product. It would, perhaps, have been even more helpful if he had been more constructive with practical suggestions for action.

He perhaps indicates the most promising approach in his words, 'All too often there is misunderstanding between purchaser and steelmaker, because neither appreciates the other's problems'. In many of Mr Brown's difficulties the steelmaker's problems need explaining. He has emphasized the question of carbon control and has quoted US methods as an example, and I shall concentrate on that.

We must consider the scale of the problem so far as the alloy steelmaker is concerned. A very large proportion of the steel supplied is fabricated without any adverse criticism from the user. Last year my own company experienced rejections by the customer of the order of 1½% in the case of both billets and bars. Internal rejections, before the customer received the material, were at least three times as great. Bearing in mind that to the steelmaker these are rejections of the finished product and not merely raw material rejections, it will be seen how much more urgent it is to him, even than to the user, that a cure should be found.

Improved methods of steelmaking control, which are economically practical, are continually being sought so as to provide the close limit analysis and the specific hardenabilities said to be so attractive to the user engaged in quantity production. The shortcomings of British specifications in carbon limits are illustrated by Mr Brown and he has outlined the American system. It is significant that he restricts himself to saying that 'Close limit steels are more readily available in the USA' and that he avoids giving direct support to the inference, so often drawn, that steelmaking control is actually better there.

It is such inferences which have led UK steelmakers to considerable expense in studying US techniques at first hand. Last year I spent several weeks with US steelmakers and users investigating these problems. Many ideas were exchanged, but I found no means of more positive steelmaking control than those already being applied here. In fact, the Americans were just as anxious to improve as we are and were full of admiration for the success achieved by melters in the UK in using, as raw material, pig irons containing high percentages of phosphorus. They could visualize only the greater difficulties of carbon control when dead block techniques are made impracticable through the danger of phosphorus reversion from the slag.

The American Iron and Steel Institute has measured statistically their steelmakers' performance in meeting the close analysis ranges of their specifications and shown 15·6% off heats in 13743 OH alloy steel casts. The steelmakers would be in economic difficulties with 15·6% off heats if it were not for the fact that a ready market exists through the series arrangement of their specifications. For those not familiar with the American series system the following table shows an example of some of their carbon steel specifications.

AISI Specification	C, %	Mn, %
C.1030	0·28–0·34	0·60–0·90
C.1031	0·28–0·34	0·30–0·60
C.1035	0·32–0·38	0·60–0·90
C.1038	0·35–0·42	0·60–0·90
C.1040	0·37–0·44	0·60–0·90

The carbon contents either abut or overlap and thus if the steelmaker is aiming at a narrow carbon range and goes outside it, one side or the other, he still has a ready market for the steel.

It is fundamental to US practice that adjacent specifications in each series are provided as an outlet for the off heats. In other words, their specifications recognize the necessity for some selection, in addition to the steelmaking art, for close limit requirements. In the same way, in the UK the user should appreciate that orders for steel to a single SAE specification are unsatisfactory to the steelmaker without order cover for adjacent specifications.

The motor industry in the USA played a leading part in seeing that this essential cover was provided, and in cooperation with the steel industry it sponsored its own specifications. It seems, therefore, that the advantages enjoyed by the American user, in fact, reflect a higher degree of sophistication in the US approach to engineering design and its related steelmaking problems. Soon, perhaps, collaboration between the purchaser and steelmaker, which Mr Brown advocates, will lead to the development of a new range of British Standard Specifications incorporating the concept of several series of related steels.

Turning now to the question of hardenability, I wonder how far the introduction of the Jominy test by the American user was influenced by the merit he saw in the British specification system. Before its introduction he had no guarantee from the steelmaker that the desired physical properties could be realized. Work in the UK with Jominy tests has been quite extensive, my company alone having results on thousands of production casts and having supplied thousands of tons to

AISI 'H' band specifications. Even so, it is doubtful whether the comparisons between UK and US steels, in the precise way Mr Brown asks for them, are possible. I am not clear whether he is seeking to know whether, in UK steel compared with US steel, there is more heterogeneity within a cast or whether there is more from cast to cast. Our results, so far as they go, seem to answer the second of these questions. I can see no valid reason for the first.

It is well known that, to ensure satisfying mechanical property requirements, UK steelmakers work to restricted chemical analysis ranges within those specified for the En steels. The ranges at which they aim are, in fact, no wider than those of US specifications. In the case of an individual steelmaker, therefore, it is reasonable to expect that the scatter of Jominy hardenabilities between casts of one quality will not be excessive. We have been working on 24 different En specifications and believe this to be so, as the bands obtained are of similar widths to AISI 'H' bands. Based on these bands, the table below illustrates our performance in the case of three typical through-hardening steels and three case-hardening steels, where more than 80 casts of each have been tested.

	En18	En19	En24	En35	En351	En352
% Casts meeting band						
(a) Within analysis	71	80	78	88	89	89
(b) Outside analysis	16	5	7	5	8	10
% Casts outside band						
(a) Within analysis						
(i) high	2	10	0	0	0	0
(ii) low	2	0	12	7	2	0
(b) Outside analysis	9	5	3	0	1	1

The division is between casts meeting band and casts outside it, and a further sub-division is between those which meet the analysis and those outside it. For instance, in En35 we have successfully met the analysis in 95% of the casts. The other extreme is En18, where we fail in 25%. We have been a little more successful in meeting the band; we have missed in the case of En352 1% of the times and in the case of En19, 15% of the times.

Our experience with AISI 'H' bands is less extensive so that with only 20 casts tested in some qualities the results cannot be regarded as quite so significant:

	SAE 8645H	SAE 8617H	SAE 8620H	SAE 4620H
% Casts meeting band				
(a) Within analysis	80	85	72	82
(b) Outside analysis	7	5	4	0
% Casts outside band				
(a) Within analysis				
(i) high	3	5	19	15
(ii) low	6	0	3	3
(b) Outside analysis	4	5	2	0

Here the performance in meeting the analysis is even better, although it is not so successful in the hardenability band.

There seems to be enough information to show how closely UK performance matches that of the USA, and that there is a consistent pattern irrespective of whether one works to UK or US standards. One general tendency we have noticed in our carburizing steels which comply with AISI analysis limits is that the hardenability bands we obtain, though no wider than the 'H' bands, show a marginal bodily movement towards higher hardenability.

We wonder whether the difficulties being experienced by the users, if indeed these are any greater than experienced by the users in the USA, could be traced to the different alloy balances chosen by different steelmakers. US steelmakers have found that substitution of one steel for another purely on the basis of hardenability when other conditions, particularly heat-treatment, are standardized, is not entirely satisfactory. Consequently, we would also like to know if any of the users can give a little more specific evidence in support of their contention that there is more adequate control of hardenability in US steels.

In 1956 we tried, in our own interests, to assess the relative effect of specification by hardenability or mechanical properties on our performance. Test results of both types were available in 156 production casts which gave the following picture of rejections:

	Casts tested	Casts rejected: On hardenability	Casts rejected: On mechanical tests
Total	156	18	25
Within analysis range	119	0	9
Outside analysis range	37	18	16

When we are outside the analysis range there is little difference between the performance of hardenability or mechanical tests. In the range, however, the mechanical test system is more selective.

The main cause of the higher rejection rate by the UK system was because it takes account of ductility and impact resistance, factors not provided for in US specifications. If the user prefers the American system we shall be willing to 'go along' with him, provided he will do something to ensure that we are covered for that series arrangement of specifications, as in the US steels.

Mr **Brown,** in reply: I feel relieved because Mr Sewell has let me down very lightly. He opened his remarks by referring to the difficulties of the user metallurgist, but I assume that he includes the people in the machine shop and the heat-treatment shop, too, and is not restricting his remarks to the metallurgist in the laboratory. It is not the metallurgist who makes complaints in that respect; complaints arise very often as a result of what happens in the factory.

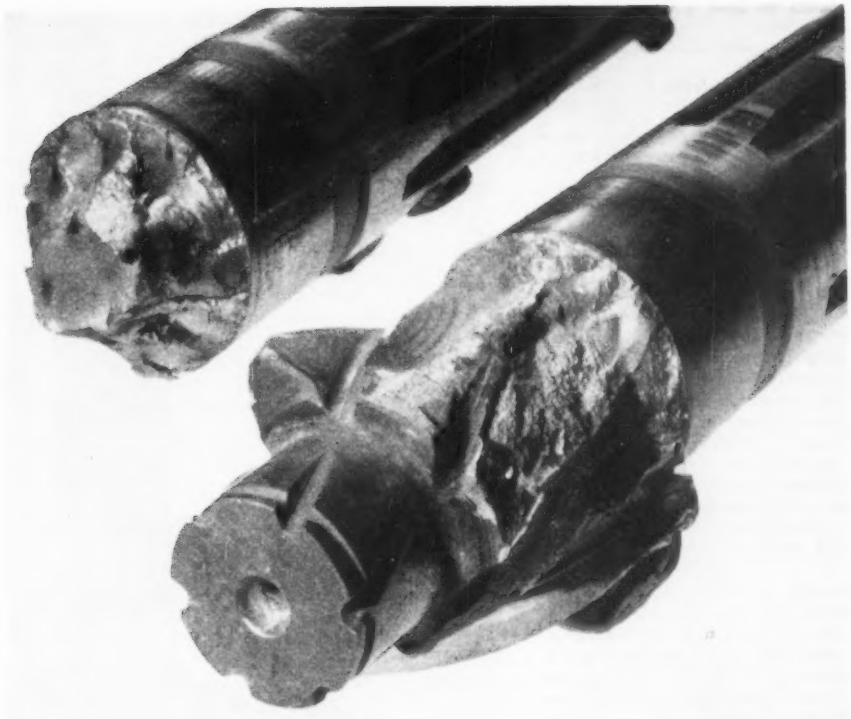
He referred to the remarks in the paper about the desire for helpful action. I feel that that can come only from the steel manufacturer. As users we cannot teach them how to make better steel; they know more about it than we do. Although we may not seem very moderate in our criticisms at times, as users we are prepared to admit that the steelmaker endeavours to give us the properties that we want. We can define what we want and why we want it, and it is up to the steelmaker to provide it even if we become increasingly demanding in our requirements as our methods of production improve. I feel sure that the steel industry can and will satisfy these demands eventually, although perhaps not in our lifetime.

I was interested in the rejection figures which Mr Sewell gave, and which are excellent. I do not know whether they would apply to other steelmakers, but we are aware that his company have always dealt in the production of high-quality steel and have always been in the vanguard on the introduction of new techniques and the making available of new ideas, often imported from the USA. They should be complimented on that fact.

I do not dispute Mr Sewell's comments that the Americans are no further forward in controlling melting procedure than is the steel industry in the UK. I also fully appreciate that the British steelmaker has problems which do not beset the American manufacturer, who has the advantage of a much purer material to start with and whose job is therefore simpler.

Reference has been made to the overlapping of American specifications and to the fact that the lead in this respect came from the motor industry. That is most desirable. The motor industry is an industry which uses vast tonnages of engineering steels and which would like to see this overlapping system adopted. In the past, when the user wanted close carbon control all sorts of additional tolerances were quoted, and the revision of B.S.970 went some way to introduce closer carbon control by subdividing the steels, but in most cases at the expense of the specification for mechanical properties. I could not see the logic of that arrangement in practice, but that is the price which we had to pay. As users, however, we must ensure that we get the required specification properties, even though the steelmaker does not always guarantee them.

'Sophistication in design' sounds an interesting term but I am not quite sure what it means. We do not regard ourselves as particularly sophisticated in the motor industry in the UK, and manufacturers are even less sophisticated in the USA, but



A *Fatigue fracture of spiral bevel pinions*

the approach in the USA has been dictated to a large extent by the desire of manufacturers for economic production and for reduction in the price which they are prepared to pay for their steels. Therefore they have had not only to watch design closely but also to develop the tests to which they subjected the steel to see whether the leaner alloy steel would do the same job as the richer and more expensive steel. Lean alloy steels came into the industry at the same time as improved heat-treatment techniques, some of which have been imported into this country and are being widely adopted particularly by the motor industry. Our requirements will increasingly be for a close carbon control and for hardenability control.

Mr Sewell knows more about the origin of the Jominy test than I do. Its main use in the USA was for matching steels for the manufacture of given components. It seems an excellent test for that purpose and from it has come the H-band specifications. Although hardenability is related to the carbon range, the adoption of H-band specification might lead to wider tolerances for this constituent.

I was interested in the tables showing work done by Mr Sewell's company on hardenability. I am not surprised that there is a reasonably close match between US and UK steels. If the composition is within the range limits, I would expect the H-bands to be similar. I am interested in the fact that there is a shift of the band and I wonder whether that is due to higher permitted residuals in the UK, as shown in my paper.

Generally speaking, in our organization we do not order to hardenability bands, although in one factory all steels for a particular component are tested for hardenability. Usually the hardenability bands are closely maintained, but if the band is outside the specified limit, the mechanical properties of a 1½-in. test bar are also outside the specified limits. We might therefore argue that we can successfully adopt either H-band specifications or mechanical property requirements or both.

Mr Sewell suggested that the time was ripe for setting up a new series of specifications, possibly a revision of B.S.970, for overlapping specifications. As a user I would welcome that, particularly if we could order close limit steel without on-costs. This will also require co-operation so that when an off-cast is produced and falls within the next grade it can be used for another component.

I was interested in the comment that the steelmaker works to close composition in his melting. Obviously he does not work to the wide limit of B.S.970 but fixes a figure within that band, but how often does the final cast come outside that restriction? Why is there so much difficulty in obtaining early agreement to a close limit specification? A certain company said that we could not have a close limit carbon steel because it was not necessary for the job, and that limits of ±0·025% were too tight (although why the supplier should know better than the user is often a point for debate). In the end they said 'We will give you what we think will do'. We received a steel with limits of ±0·03% which was satisfactory for the job, and cast after cast of that steel was produced without any difficulty in steelmaking as far as we know.

Mr **G. Bell** (Standard-Triumph International): Mr Brown has drawn a comparison between UK and US steel specifications with particular regard to carbon and residual element limits and their effect on controlled heat-treatment, a factor which is very important to the motor industry. I hope to emphasize his remarks on the importance of close control of these factors which, by their effect on the hardenability of steel, materially alter the fatigue life of highly stressed components. My own experience with the low-alloy carburizing steels suggests that the hardenability and physical properties of a particular cast of steel have a much greater bearing on the ultimate performance of the component that its chemical analysis, and personally I am all for specification of physical properties and hardenability ranges at the expense, if necessary, of narrow composition limits. One point which requires a more precise definition is what is meant by the term 'hardenability'. This can apply either to the degree of surface hardness or to the depth of effective hardening, where the manganese and molybdenum contents play a major part, in addition to carbon.

Two examples will help to demonstrate the importance of

TABLE 1 Comparative results on bevel pinions, SAE 8622 specification

No.	Rig life, h	Calculated hardenability number	Rockwell equivalent hardness Core	Case	Case depth Flank, in.	Root, in.	Retained austenite, %
1	15	1056	27	61	0·050	0·034	10–15
2	23	1068	32	62	0·051	0·035	Trace
3	38	1120	35	62	0·050	0·041	Trace
4	77	1171	48	62	0·073	0·057	5–10
5A	6	980	24	62	0·045	0·035	Trace
5B	10	980	24	61	0·075	0·065	5–10

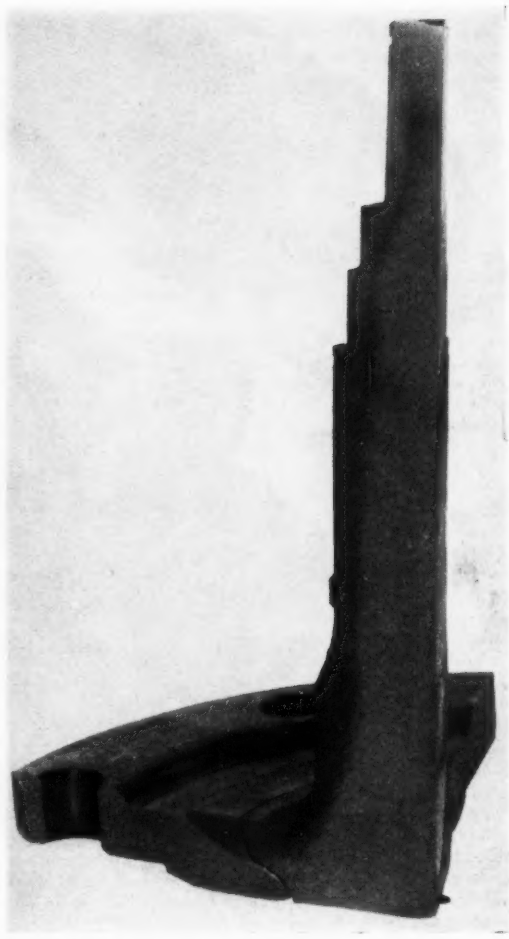
hardenability on fatigue life. Figure *A* shows the fatigue fracture of spiral bevel pinions. It shows the classic half-moon fatigue nuclei starting where the maximum bending moment occurs. This example was taken from our fatigue rig after testing at a load many times greater than that normally met under service conditions. Early work on isolated instances of failures on this component revealed very little on which to base a sound reason for failure, and I have no doubt that a few years ago the design would have been revised or a more costly steel specified, leading to a less economical component. It was only after we had done several hundred fatigue tests on a number of casts of steel and various types of heat-treatment that we began to build up a statistical picture of the basic reasons for failure.

Table 1 gives some examples of the average fatigue life results obtained on spiral bevel gears made from a number of SAE 8622 steel casts but processed under similar heat-treatment conditions, carefully controlled. It will be noted that in the case of cast no.1 the average rig life figure is 15 h, the calculated hardenability number being 1056. It will be seen that as the hardenability number increases, the average rig life increases, showing that a relationship possibly exists between the hardenability number and the rig life, although, of course, a number of other factors are involved. At first sight one may say that this is to be expected owing to the increase of core hardness and therefore strength. I shall return to this point a little later.

If the effective case depth in the root of the tooth, measured at the section where the maximum bending moment occurs, is examined, it will be seen that this also tends to increase, showing a relationship with the core hardness, which is measured at a specific point in the core of the tooth. I should perhaps mention that these effective case depths are measured by hardness traverse, so that the higher the core hardness the higher becomes the effective case depth. Nevertheless, all these figures of core hardness and case depth are completely dependent on the hardenability of the steel itself.

In cast no.4, which had a rig life of 77 h, one could comment that the case depth of 0·057 in. was the factor having the greater effect on life. To show that case depth is not in itself the answer to improved fatigue life, I should like to quote the example from cast no.5. This had a hardenability figure of 980 and gave a nominal core hardness of 24 Rockwell C. With an effective case depth at the root of 0·035 in., the average rig life was 6 h. With the effective case depth in the root increased to 0·065 in., the rig life increased only to 10 h. This shows that although case depth is of great importance, particularly at the tooth root, a thick case in itself will not cause a steel of too low hardenability to perform satisfactorily. Our work has tended to show that it is often advantageous to have a thinner case where a high-hardenability steel is involved. I would add that all these casts of steel were within the analysis specification for SAE 8622; the carbon contents were within a few points of each other.

In an attempt to evaluate the top hardenability number suitable for these components, it was found that above a certain figure the fatigue life dropped rapidly. Components removed from the rig before actual failure were found to have numerous hairline cracks on the tooth faces, indicating that the greater volume change of the core had imposed residual tensile stresses in the case.



B *Cracking in component with integral axle flange, arising from residual tensile stress due to cold tension*

The method of evaluating a steel cast by its calculated hardenability factor is open to criticism but it was used in this instance to enable the steelmaker to make a quick assessment of the cast's probable reaction to heat-treatment, so that if the calculated hardenability number were outside certain limits which had been determined experimentally, the steel might be diverted to a less highly stressed component. This is a decision which it is essential to take before rolling begins, since a different billet size may be required. It is possible to show, however, that there is a certain rough relationship between the calculated hardenability factor and the Jominy test figures. It must be emphasized that the hardenability factor can be used only where there is a background of experience on a particular component. It does not apply as an empirical rule on every type of component.

To turn to plain carbon steels and the effect of residual elements on the hardenability, particularly in the case of high-frequency hardening, I should like to demonstrate the effect of hf hardening on a component where two casts of En43C steel were involved, one with a higher hardenability than the other.

Figure *B* shows a component with an integral axle flange. The flange is required to withstand a test condition which specifies a high bending moment for a high number of revolutions, and it gains its strength from the induction hardening of the stress-raising contour between the flange and the shaft. In this example, the cast of steel from which the component was

manufactured had a low hardenability factor, which necessitated a deeper heating pattern than normal, so that the ratio of the heat-affected zone to the martensitic zone was greater than unity. The result is that the local effect of the induction heating surrounded by cold metal allows hot compression, causing plastic deformation of the hot zone and resulting in cold tension on cooling. The resultant residual tensile stress due to this cold tension is the cause of short rig life.

Figure *C* shows a similar component produced from a cast of steel with higher hardenability, although covered by the same chemical analysis range as the previous example. In this case it will be seen that the heat-affected zone is very little more than the martensitic zone, and the consequent shallow depth of heating necessary to achieve practically complete hardening results in a tendency for the residual stress after quench being compressive rather than tensile, thereby improving the fatigue life by a ratio in the order of 10:1. This is a fantastic increase when one considers its effect on service life.

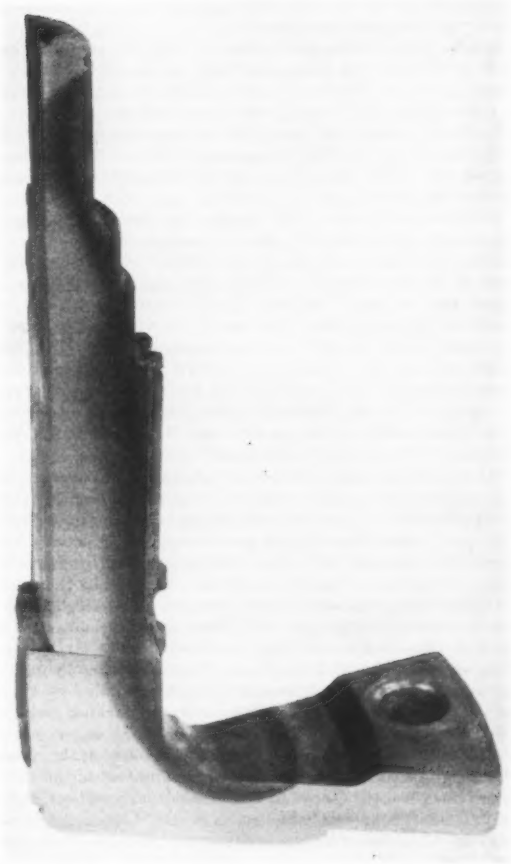
Both of these examples had a chemical analysis very similar with respect to carbon and manganese, which are the only two elements normally checked on a plain carbon steel, and indeed the only two elements other than silicon, sulphur, and phosphorus which one can control without having to pay a premium. However, when we considered the effect of the residual elements, nickel, chromium, and molybdenum, it was found that the calculated hardenability factor was 960 in the first example and 1100 in the second example. Based on Rockwell inch tests, the diameter of bar which would just harden to the core in the case of the low hardenability material was 0·98 in. dia., but in the case of the higher hardenability material the critical diameter increased to 2·1 in. The difference in hardenability of these two casts of steel was due to the difference in nickel, chromium, and molybdenum content. None of these elements, of course, can be specified in the case of plain steel either in the UK or, as far as I know, in the USA.

Mr Brown has made no reference in the paper to the control of the degree of banding which one can tolerate in steel. Yet this in itself often raises severe problems with regard to machinability and heat-treatment, particularly where automatic machining and fixed cycle heat-treatments are involved. I should like his views on this point.

I have very little comment to make on the part of the paper which refers to cold flow forging, as this technique is new to me. Although it is not directly related to the subject under discussion, I should be interested to know whether Mr Brown has produced a formula whereby he can decide whether cold forging of a particular component is a more attractive economical proposition than other productive methods. It appears to me from various examples which I have examined that the suitability of this process largely depends upon the bulk of metal which has to be removed. It undoubtedly has obvious advantages when considered for components at present produced from bar stock, where a large percentage of stock removal occurs, but it is unlikely to show a saving over hot forgings produced in closed dies, unless an expensive machining operation can be eliminated, e.g. long small-diameter splined bores.

I congratulate Mr Brown on an excellent paper, which I hope will result in some profitable discussions between the automobile industry and the steel manufacturers. To be fair to the steelmaker, however, I have found that provided one can give him a true appreciation of the problems involved in any application, he will then render the maximum assistance to give the user the qualities he requires.

Dr **J. Cameron** (The Clyde Alloy Steel Co. Ltd): I shall deal first with the question of carbon content and, in particular, the question of close limit specifications. I am in entire agreement with Mr Brown about the unsatisfactory and vague wording of B.S.970 on the tolerances to be expected on analytical checks. This vagueness causes as much annoyance to the steel supplier as it does to the steel user, and the supplier would also welcome the establishment of precise values such as are laid down in the AISI 'Steel products manual'. However I gather



C *Similar component made from steel with same analysis as B, but with higher hardenability*

from Mr Brown's remarks that perhaps that would not satisfy him but that he would like all the steel supplied to fall within the narrow specification range. I may be doing him an injustice, but that is my reading of the paper.

If that is so, perhaps it might lead to a greater understanding of the steelmakers' problems if we summarized the difficulties with which they have to contend in meeting a five-point specification, or indeed a three-point specification, such as is fairly common in alloy steels.

First, we have the difficulty of controlling the carbon content in a large basic OH furnace where the carbon content is dropping rapidly. The problem can be made easier by using an acid OH or an electric furnace, using a double slag process, but the extra cost involved in the more expensive raw materials required, or the additional cost of power, makes it impossible economically.

The second problem is that of segregation in the ingot. Liquid steel is a solution of carbon and other elements in iron, and unfortunately the physio-chemical laws of solidification are such that in the process of solidification considerable variation in carbon content occurs throughout the ingot both in a vertical direction and across the section. In subsequent processing, the variations across the section are reduced, but the vertical variations persist in the finished product. These facts are fully documented in the reports of the Heterogeneity of Steel Ingots Committee. Generally, the degree of segregation increases with the increasing ingot size. Unfortunately, the price of carbon steels is such that they can only be made economically in high-production mills which require large ingots to maintain an economic production rate. Alloy steels

are usually produced in smaller ingots and consequently the variation in composition is less.

Lastly, there is the problem of accuracy in sampling and analysis both in the liquid steel and in the steel product as examined by the customer. Consequently, if tolerances similar to those of the AISI 'Steel products manual' are laid down, it will also be necessary to specify the exact sampling procedure. In passing, I should also like to point out that B.S.970, being a British Standard, is as much the responsibility of the steel users as the steelmakers.

Mr Brown draws attention to the fact that the maximum permissible percentage of tramp elements is lower in the American specifications than in B.S.970 and states that such a state of affairs is viewed with envy by British steel users. It might also be mentioned that the American steelmaker has available raw materials which make his British counterpart extremely envious. The lower tolerances in the USA also reflect the higher proportion of hot metal used in that country. I think that the advantages to the American user, however, are perhaps rather illusory because, while B.S.970 permits those high levels, actual supplies are very much lower and normally would readily meet the AISI specifications.

Mr Brown appears to object to paying an extra price for controlled grain size and considers that it should be part of the normal production procedure. It might be pointed out, however, that these extra charges are not applied arbitrarily but reflect the increased cost of producing steel with controlled grain size. Grain-size control is normally achieved by the use of aluminium. Consequently, it can be applied only to fully killed steels, thus involving lower yields and the additional cost of hot-tops, etc. Moreover, aluminium additions make liquid steel very sluggish and cause poor ingot surfaces owing to lapping. Aluminium additions of the order required to effect grain control increase the incidence of ingot cracking and can also cause trouble in subsequent cogging of the ingot, owing to the presence of type-2 sulphide inclusions at the grain boundary. All these factors increase the final cost of the steel, quite apart from the cost of the aluminium addition itself, which is no inconsiderable factor.

On the question of inclusion count requirements, it is difficult to say whether an extra charge would be justified or how much such an extra should be. Obviously the answer depends on what standard of cleanliness is demanded by the customer and certainly it should not be necessary to specify an inclusion count to obtain steel supplies cleaner than that illustrated in Fig.5 of the paper. However, while Mr Brown states that that sample was not specially selected, I refuse to believe that Fig.5 is representative of the products of the UK steel industry. Such is certainly not my experience. I think it would be fair to say that the British steelmakers' reluctance to accept orders for steels involving an inclusion count is not due to lack of confidence in the steel but to lack of confidence in inclusion counting methods.

The reproducibility of inclusion counts carried out by different operators, even on the same sample, is extremely poor, and by repolishing the sample an entirely different order of results can be obtained. The difficulties of sampling are enormous, and no steelmaker would relish the idea of having a whole cast of steel sentenced on the basis of the examination of one or two square inches of polished surface. Where such orders are accepted, the work involved in ensuring that the steel conforms to the customer's requirements, together with the dislocation to the normal flow of production, are very poorly compensated by the present extra charges recoverable.

Mr Brown states that Figs.1–3 are typical of the material purchased as forging quality steel. If that is true, then indeed he has just cause for complaint. However, again I am extremely sceptical on this subject. In my experience over many years in the supply of forging steel to the motor industry, I know of no customer who would tolerate steel of the type illustrated. Certainly the firm with which I am associated are makers of alloy steels as well as carbon steels and, consequently, would perhaps qualify for the rather left-handed compliment paid by Mr Brown. This is perhaps borne out by the fact that over the many thousands of tons annually supplied by us to the motor industry, including Mr Brown's company, the percentage of material rejected is virtually nil.

However, it is only fair to the carbon steelmakers to point out that the greater freedom from defects enjoyed by the alloy steel user is achieved only at a price. The present price of carbon steels is such that they can be made profitably only in high-production melting shops and rolling mills. Alloy steels are generally made in much lower production units and many firms have found to their cost that it is impossible to process carbon steels in alloy steel plants and still make a profit.

In conclusion, we might say that throughout his paper Mr Brown has chosen to ignore completely the economics of steel production and has attacked the principle of making extra charges for additional requirements. This is surely a most unreasonable attitude. Since these additional requirements involve additional production costs, it would be most unfair if they were included in the general basic cost of steel and so had to be paid for by the users who do not require and so would not benefit from such additional refinements. I am not aware of any reason why the motor industry should enjoy such a hidden subsidy from the other steel-using industries.

Mr **D. H. Lee-Bird** (Smith's Stamping Works, Coventry): The drop forger is expected to produce forgings to very close limits so that machining can be cut to a minimum. The composition must be such that any heat-treatment can be standardized and that automatic heat-treatment processes can be used. It is therefore logical for the drop forger to expect a similarly high standard of product from the steelmaker, who supplies his raw material.

One point which has been argued for a long time concerns what is meant by forging quality steel. This is a description which has not been precisely defined. It is now a misnomer, because it does not cover all types of forging, particularly now that we have cold forging. If a forging is to be produced by up-ending, it is not enough to specify forging quality. The forger must specify up-ending quality steel, otherwise the steelmaker will not be responsible for any defects produced through forging by the up-ending process.

It seems to me that the difference between forging quality and up-ending quality is purely one of inspection. Forging quality steel is examined in the black state, usually by grinding a small area at intervals along the billet. The operator examines the billets and if, in his opinion, the defects are not very great and are not detrimental, the steel is passed. If the defects present are considered to be detrimental, they are removed. Up-ending quality billets are pickled and the defects then removed. The forger has found that if he is to produce forgings which will not subsequently be machined on the surface, it is essential to order pickled and chipped billets.

A number of US firms operating in the UK insist, with regard to hardenability, on US standards being met in the UK. Whereas they are prepared to accept British chemical compositions, they insist on fine-grain steels, a standard of cleanliness, and a hardenability clause. The latter may be a simple statement that the steel will be capable of hardening to a certain hardness when quenched from a certain temperature, or there may be a Jominy test, which must be within certain limits, particularly if surface hardening by induction heating is to be done. The steelmakers co-operate in this, and the Americans say that it is worthwhile to pay more for steels of this quality because fewer rejections occur and it is possible to standardize the heat-treatment processes.

This form of specifying is very helpful and is well worth considering. The drop forger has no control over the specification to be used; his customer controls that. It is very important that the customer should give very precise details of what he wants so that this information can be passed to the steelmaker. It has also been found that a number of firms competing in the American market must supply steel to the American specifications; it is not satisfactory to use the equivalent British specifications for the simple reason that certain elements are outside the normal requirements of the American specification.

Some inspectors who have no knowledge of metallurgy want to reject forgings if there is the question of certifying that there are very slight discrepancies in the analysis. This matter should be taken up so that everybody knows where they stand.

The steel requirements of the forging industry should be clearly defined so that the users and makers of steel are in agreement on the interpretation of these requirements. We should like to get away from the impression that steel is available at a price but that if we want good steel, then we must be prepared to pay a lot extra for it. That might seem a little unfair, but we have to pay extra for many of these things, and if everyone knew exactly what the position was at the start and the exact requirements, it would be to the benefit of all.

Mr **D. C. Harries** (English Steel Rolling Mills Corporation Ltd): I should like to record the progress which is now being made in meeting increasingly stringent chemical specifications by means of the direct-reading spectrometer. This is now established as a production instrument giving valuable assistance to the steelmaker in controlling elements within closer limits than before, and in eliminating much of the human error associated with wet analysis. Bath sample analyses are made available to the steelmaker much earlier than by chemical methods, and accidental elements, if present, are quickly detected, making it possible, where necessary, to switch to another specification.

On the specific problem of accidental elements, notably tin and copper, the steel industry has to rely not only on its own scrap, but also on that purchased from outside sources. Much of this comes from the engineering industry, and anything that can be done to avoid the contamination of ferrous with non-ferrous materials will be of great assistance.

On the specifications themselves, the overlap, which is more typical of the US than of our own, is a decided advantage, as Mr Brown has stated. We have to move more in this direction and the various trade associations are now considering how this can best be brought about.

Mr **J. D. Bunton** (Garringtons Ltd): Several of the points in the paper relating to steel quality confirm what has been evident for some time: that there is a growing disparity between what is required by the user and what can be regularly supplied by the steelmaker. During the past 10 to 20 years there have been changes in the manufacturing techniques in the drop-forging industry and in the engineering industry, as a result of which a better quality steel is required. Although these changes have been made in the interest of greater productivity and economy, they do not appear to have been accompanied by any marked changes in steelmaking technique in respect of quality. Consequently, although the quality of the steel may not be dropping, it is becoming increasingly unsatisfactory to the user in several respects.

For example, consider the surface quality of steel as it affects, for example, the manufacture of a connecting-rod, which is typical of many highly stressed components for the engineering industry. Several years ago the connecting-rod would have been designed in an alloy steel and it would have had an ample factor of safety. It would have been drop-forged from a billet or bar which would have been heated in an oil-fired furnace. Its machining allowances would have been ruled to a large extent by the permissible forging tolerances. Its heat-treatment would not have been unduly critical. Service failures would have been unlikely.

Today, in the interest of greater productivity and economy, the technique of design and manufacture is quite different. The factor of safety is usually lower as connecting-rods are more highly stressed. First, whereas in the past there would have been polishing all over the surface, today there is no overall machining. Second, the connecting-rod may be made from plain carbon steel. Third, the billet or bar used in its manufacture may be heated by induction with a minimum of scaling and, therefore, the minimum of removal of surface defects. It may be press-forged from a pre-formed use instead of drop-forged.

Fourth, the press-forging technique, although an improvement over the heating in oil-fired furnaces followed by hammer forging from the viewpoint of consistency and material utilization, is nevertheless more exacting on surface quality. Fifth, the closer tolerances possible with press-forging induce reduced machining allowances and, therefore, less removal of surface defects. Sixth, the heat-treatment tolerance is considerably reduced. The required hardness is achieved only by water-quenching and there is more danger of cracking, which may be accentuated by surface defects. Seventh, surface defects are known to be stress raisers in service, and therefore the standard of inspection of this highly stressed component is raised to the extent that after pickling and magnetic crack detection, any surface defect will be the cause of rejection.

To be almost certain of meeting such conditions, the steelmaker would have to supply ground billet at considerably more cost. Consequently, although costs are being apparently reduced at the user's works, they are being increased at the steelworks and of course being paid for largely by the user.

The user's idea of what the inclusion content of a steel should be and what is practicable for the steelmaker are often poles apart. The machinist requires adequate sulphides and a minimum of silicates and oxides. This sounds quite straightforward, but unfortunately it is not so easy in practice. Even with the best will in the world, the steelmaker cannot guarantee freedom from undesirable inclusions which cause damage to cutting tools.

In my opinion, a great weakness is the lack of an adequate system of inspection. With present-day methods it is impracticable to determine with any degree of accuracy the surface quality or inclusion content of any cast of steel. The procedure is usually, first, the cursory surface examination of the billets or bars, and then selection of a few samples for pickling, hot upsetting, magnetic ink crack detection of step-turned test pieces, and microexamination. Although the best that can be done with present facilities, this procedure is most inadequate, wasteful of steel, and sometimes wasteful of subsequent manufacturing effort. Steel is sometimes used which should have been scrapped and, conversely, complete casts are sometimes rejected although they may contain the defect to a minor extent.

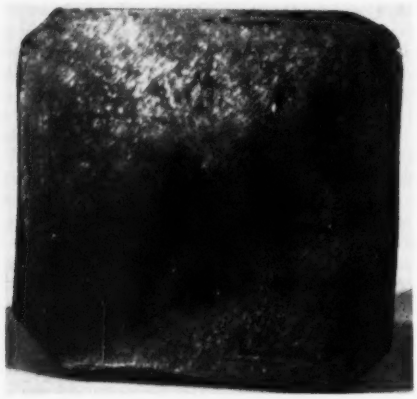
What is the answer? Can the steelmaker, with the present techniques, be expected to produce steel economically which will be of a considerably better quality? Do we see the possibility of non-destructive testing being applied to the assessment of surface quality or inclusion content?

I have one point to make about B.S.970. In the case of En8 Q and R properties, the impact properties are not guaranteed other than by using fine-grain steel. That being the cast, I feel that that should be noted in B.S.970 so that the user can understand that he must pay extra for these properties.

On speaking to a number of people about Mr Brown's paper in the last few days, I have observed a feeling that it would be a good thing if a panel could be formed between the steelmakers and users to discuss some of the present-day problems.

Mr **F. Rodgers** (Hadfields Ltd): The UK steel industry is aware of the US emphasis on hardenability. Hardenability is a measure of the control of the depth of hardness, not hardness level, and possibly that deals with a point raised in the discussion. It is known that hardenability is dependent on the composition of the steel, and mainly on account of the work done by Grossman in the USA, it can be calculated with a fair degree of nicety from the chemical composition. It can be varied over a very wide range, and within the framework of any suitable composition, by varying the carbon and alloy content one can achieve a fairly standard hardenability.

It has been the practice in the UK to use the criterion of mechanical strength as the measure of the ability of a steel to perform a certain duty. Hardenability is not necessarily a criterion of the mechanical properties of a steel that the user can expect, but one can gather from the hardenability some indication of the tensile strength. One can also gather some



D *Section of rejected billet*

indication of the proof stress and the yield point, but not necessarily the ductility as measured by either elongation or impact.

A review of the experience of my company over a number of years has shown that the impact test in particular is the main cause of dissension, or rejection of casts, between our customer and ourselves. That would not arise should we release on the basis of hardenability. My company, like various others which are represented at this meeting, have supplied, with very little trouble, steel to the various AISI hardenability requirements when specially requested.

Steelmakers have the requirements of the user industries very much in mind. We are aware of their demand for a better product, and I have little doubt that in 100 years' time this argument will still be proceeding.

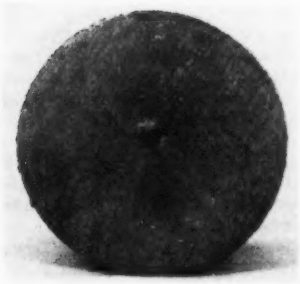
Mr **E. G. Bayliss** (Forgings and Presswork Ltd): There is no agreement on whether forging quality material should be bottom- or top-poured, and I should like to know what prohibits such an agreement. My experience is that most of the trouble over the years has been with material known to be top-poured.

We have been told about forging quality and upsetting quality requirements. Much of our processing is even more severe in what we term 'lay-in forging', with the bar laid horizontally between the dies, than in many of our upset forgings. I think that the distinction is artificial.

Our normal rejections due to seaminess are about 0·2%. That does not sound much, but it involves a lot of money and a lot of recovery by grinding. The drop-forging industry depends for its living on maintaining its competitive power, particularly over casting, and that means that we must make closer and more accurate forgings. The question of surface quality will become more important, and correction of decarburization may play an increasing part in manufacture. It is economically sound to correct as late as possible in the production sequence. That is particularly important in view of the wastage of material through processing from start to finish.

Regarding cleanliness, people usually talk about inclusion counts. I should like to know who is trying to hoodwink whom. Most of our troubles over the years have not been with microscopic inclusions but with macroscopic, and the position is getting worse. Much of it is due to inadequate inspection. We appreciate the problem; as one approaches the end of the line it is easier to inspect and the inspection becomes more reliable.

Several companies appear to be in trouble with the problem shown in Fig. *D*. The white spots are refractory in type, and can be seen during shearing, when the steel is rejected. I refuse to put that sort of steel into a modern high-production machine. The effect of such inclusions on high-speed tools is catastrophic: a breakage can cost £50 a time. If we are obliged to have that sort of material delivered to us, and assuming



E *Example of fault frequently found in forging quality steel 'as supplied'*

that it is refractory, I suggest that the refractory maker should incorporate a fluorescent so that we can pick it out in ultraviolet light!

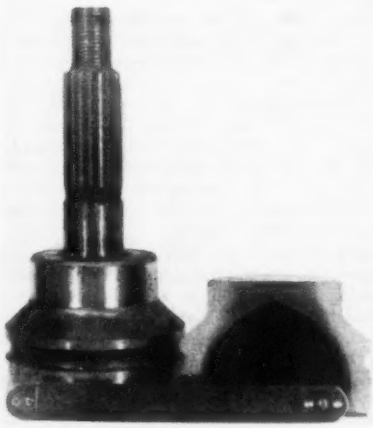
Figure *E* shows the sort of thing we are receiving every other week from reputable suppliers. In my opinion it is not forging quality steel, and I wish that some of the brains in the industry of which there are undoubtedly plenty, would get on to the shop floor and cure this once and for all.

Figure *F* is of En35, carburized, and it is an important driving member in a car. The section shows where a threaded nut was fitted. On one occasion it was necessary to remove that nut from the top end, and the threaded end dropped off; it was found that the hardness of the core was 58 Rockwell. The carbon content in the light zone was 0·19%C and in the dark axial area it was 0·68%C. The alloy content was correct.

I should like to say much more about magnetic crack detection for I consider that many perfectly serviceable forgings are being thrown on the scrap heap because the magnetic crack detection test is non-discriminatory. Everything is either black or white. Many forgings are being thrown out, but one has only to look at them to realize that they would break not at the indicated point but, for design reasons, at the opposite end. I plead for more rig-testing so that the rejection is made with full knowledge and not based on ignorance.

Dr **B. B. Hundy** (Steel, Peech and Tozer): Many speakers have emphasized the vexed question of forging quality, but in effect the user has to pay the price and, generally speaking, the steel industry and the user industry have to come to an agreement on what is needed for a particular type of forging.

While there are no approved limits for residual elements in B.S.970 for carbon steel, all steelmakers of repute work to their



F *Fault in component of En35 steel, carburized*

own internal standards and in many cases these are better than the American figures mentioned by Mr Brown, and are certainly no worse.

On the question of carbon spread found in check analysis, at the moment the technical committees of the various trade associations are actively discussing this and we hope that eventually we shall have some figures for B.S.970 or a similar British Standard specification. It is no secret that the sort of figures we are thinking about are similar to the SAE and ASTM figures used in the USA.

As far as cold forging or cold extrusion is concerned, does Mr Brown feel that the future of this process lies with alloy steels, low-alloy steels, or with mild steels of the En2A type?

Mr **Brown,** in reply: I was pleased to have support from the users' side of the industry, even though there were some slight disagreements on interpretation. Mr Bell's statement that he had found reasonable agreement between calculated hardenability number and the actual number was interesting. We have not done much with hardenability calculation; we have done a lot of hardenability testing but generally we do not try to put limits in our specifications owing to the objections on the steelmaking side. From the tone of the discussion it seems obvious that the time when we reach agreement on H-steels is not far off, although we must have an agreed understanding on what we mean by H-steels.

Banding is a difficult problem, for it interferes considerably with machinability. As users we are completely in the hands of the steel manufacturer or re-roller and we plead for his assistance to obtain uniformity of structure by using the right rolling temperature and rolling down to the right finishing temperature.

Mr Bell asked about the economics of cold-flow forging. This is related to the basic cost of the steel. If one is buying steel and 80–90% is being thrown away as machining swarf, one has cause to give serious consideration to cold-flow forging or extrusion. The technique is in such an early stage that it is very difficult to lay down hard-and-fast rules as to which parts can be produced economically and which cannot. The economics will be greater if we can obtain steel, possibly at a slight on-cost, which has an excellent surface and a uniform structure.

I can assure Dr Cameron that Figs.1–3 were taken from samples of material from forging quality stock in our stores which was intended for experimental work in cold-flow forging, and that the specimens shown were not specially selected to show defects which are regularly experienced. Figure 4 shows what results from surface defects on a cold-flow forging having an upset flange.

I am glad that there was some agreement between us on the vagueness of the relevant BS clauses and I trust that this will in time be put right. Dr Cameron said that B.S.970 was not the sole responsibility of the steelmakers and that user interests were represented, which is true, but the user interests are largely outnumbered by the steelmaking interests and B.S.970 was originally formulated by the steel industry and subsequently revised twice at the insistence of the user interests. The user did not succeed in having included many of the things he wanted, one of these being the residuals in carbon steel. I was interested to hear the reasons given for the extra charge for grain-size control, and I shall feel happier in future in paying extra for this requirement. But grain-size control was introduced before the war, and surely progress has been made in overcoming many of the difficulties experienced in the early days, even though, as has been said at this meeting, the metal-physics are the same.

I agree that the assessment of inclusions leaves much to be desired. We use the Fox inclusion count system and I do not think we have ever had a disagreement with the steelmakers on our findings. With steel users, however, the material is either clean or dirty; unfortunately much of it is in the last category! I think that a broader method of description would be preferable to a precise inclusion count, which to some extent is only in the realm of the research department.

Mr Lee-Bird referred to the problems of the drop forger. He is between the steelmaker and the user. I agree that forging quality should be precisely defined in our national specifications.

I was interested in Mr Harries' comments on the direct reading spectrometer in controlling residuals and making it possible to switch the metal to some other specification in which the residuals detected can be utilized. That is an interesting development and I trust that in the future we shall see a considerable reduction in these elements. I agree that there must be some development of the use by the user of overlapping specifications. In regard to contamination by scrap, the intelligent user segregates his scrap because he gets different prices for different types and he would not introduce tin-plate and material known to be objectionable into his scrap because he would get a lower price. The implication is that some contamination arises from the scrap which the steelmaker buys. If he is buying mixed scrap, it is at a lower price, and the necessary sorting is his responsibility.

Mr Bunton referred to the disparity between user requirements and the specification requirements of steelmakers. He supports my view that increased production has not been associated with increased quality or even maintenance in quality. I was interested in his comment that for connecting-rods, the trend was to go for carbon steel. The organization with which I am associated has gone from carbon steel to alloy steels because we want as light a section as possible, and the stresses have risen considerably. I was concerned about his comment that at one time connecting-rods were polished all over. That was so in the aircraft industry and might have been so for some heavy commercials but in the motor trade generally polishing has never been practised, and examination for surface quality has largely been in the hands of the inspector making the necessary dimensional check and who has, additionally, looked for surface defects.

Mr Bayliss supported Mr Bunton's plea for an improvement in methods of inspection for inclusions. It is a fair comment that inclusions are often massive and cause much trouble, and this is a matter of much concern to the user. If you have high-precision machines on a transfer basis and you run into a component containing a large mass of slag or of refractory from the furnace, it can destroy the tool and stop the whole production line, which is very costly. Mr Bunton mentioned his own inspection procedure, which gives some indication of what is required. I do not think either the forger or the user is requiring the impossible, and the fact that we have discussed some of the things which cause frequent irritation and delays is a move in the right direction. He also mentioned the question of the Izod value of En8. I agree that it should be clearly stated in B.S.970 that the specified impact values of carbon steels are always tricky, but one can generally get them, although only after great pressure on the steel suppliers, or by selection of source.

Mr Rodgers spoke about hardenability. I do not entirely agree with the statement that it controls the depth of hardening, for it controls more than that, and it is a measure of other properties. The user is probably more interested in the hardenability test as a method of checking the consistency of the incoming steel. I agree that it is not necessarily a criterion of all the mechanical properties; it is of tensile properties but not of ductility or impact. I believe that impact requirements are often unnecessarily high for the application of the steel.

I was interested in Mr Bayliss's comments on the figure of 0·2% rejections for seaminess; he said it did not sound much but it involved a lot of money. In our industry we should regard 0·2% of complaints on our cars as almost requiring panic action! There may be no objection to the payment of certain on-costs, and I think users are agreed about that, but we want to know exactly what we are paying for and that we are getting what we have paid for.

I believe that bottom-pouring is preferable, and may in some cases be essential, but if sound steel can be top-poured then the user is unlikely to object. His plea that decarburiza-

tion should be corrected as late as possible is valid; it is no good correcting in the early stages if one decarburizes in the later stages.

Dr Hundy stated that agreement on users' requirements should be possible. Mr Bunton had said it was time to get together to work out exactly what we want. I trust that as an outcome of this meeting the necessary steps will be taken to bring that into effect.

Dr Hundy also raised the question of cold forging and extrusion and asked if the future lies with alloy steel or mild steel of the deep-drawing type. That is an extremely difficult question. Low-alloy steels can be quite successfully extruded cold and cold-flow forged, but it is difficult at the present state of the technique to say exactly what can be done and what shapes can be produced. The deep-drawing types of steel in billet form are much easier to form than alloy steel.

Discussion on the cold extrusion of steel

This discussion was based on the following paper (date of publication in the *Journal* is given in parenthesis):

'The cold extrusion of steel', by *R. A. P. Morgan* (1959, **193**, 285–303). Mr Morgan (Royal Ordnance Factory, Birtley) presented his paper.

Mr **A. P. T. Taylor-Gill** (Canatlas Steels (England) Ltd): Though not engaged directly in the practice of cold extrusion, I was for some years very intimately concerned with the techniques of cold hobbing, which have many points of contact with cold extrusion. However, I am, of course, indirectly concerned in that I have done some work on the application of tool steels to this process.

In cold hobbing my colleagues and I were interested in the cavity produced rather than a cold-flow forged product required in large numbers, and, for the most part, only had to think in terms of some number of cavities for a particular mould with possible replacements for these at a later date. Our hobs, corresponding to the punches in the cold extrusion process, would rarely be called upon to produce more than 100 cavities, though no doubt they would have been capable of doing so.

When we started we had nothing to guide us and would take what we hoped was the hardest possible hob, in its toughest condition, with the softest possible slug, to a concern operating a 3000-ton press which had been installed in connexion with bearing manufacture. After paying our fee we watched with bated breath while they pushed the one into the other to the depth required. If lucky the result was a beautiful cavity and a hob which lived to push more cavities; if unlucky we gathered up the fragments and retired to consider if any improvements could be made sufficient to justify the making of another expensive hob.

As the minimum requirement was usually a completely perfect cavity, often incapable of being polished or improved in any way, we soon learned a good deal about metal flow, and it became apparent that there was a critical slug/cavity volume ratio applicable to the various cavity design characteristics. Thus simple shapes with ideal flow characteristics could be produced at hobbing pressures as low as 100 tons/in^2 on the hob, without any tearing of the cavity walls in slug material of the ultra low carbon (0·07 max.) type at around 120 Brinell. In such cases the slug might be of the order of 15–20 times the volume of the cavity, and almost any hob which was of sound material with a proof stress above 100 tons/in^2 would serve.

At the other extreme sometimes cavities had to be produced with virtually no flow possible up around the hob at 10/12 slug/cavity ratio. In these cases hobbing pressures would be as much as 180 tons/in^2 on the hob almost as soon as it entered the slug. They would quickly rise to 200 tons/in^2 at which penetration would normally be stopped and measures taken to reduce the hob loading. Such measures include stress relieving, or actual relieving of metal of the slug, (say by drilling a hole from the bottom of the slug to within a certain distance of the full depth of the cavity), or bright annealing, if such facilities were available.

Some of the cavities made in this way are very close to cold extrusion of closed end tubes, and I can certainly confirm from personal experience that many of the views expressed by Mr Morgan would apply with equal force in my own field. In particular sub-critical annealing of slugs gave the best results, and extreme accuracy of the press platens, as indeed of everything to do with the press, was absolutely essential. We not only used pressure pads at very high hardness between hob and platen, but surface-ground them at very frequent intervals to remove all marks and preserve accuracy of the order he mentions.

Shrouds, or shrink rings, of ample size were used in a similar material to that described by Mr Morgan for the shrink rings in his practice. The slugs fitted into these on a small taper to facilitate removal after completion of the hobbing. As the control of slug volume was vital to the maintenance of adequate pressure for the prevention of tearing of cavity walls in deep hobbing, the slugs still had to be held, even when hobbing into rectangular blocks. Standard rings of various sizes were adapted by the fitting of cheek plates to make the rectangles.

In the early days we thought that hobs should have the largest possible head to spread the load, but we soon discovered this was wrong and ultimately designed hobs which pushed against the pressure plate with an area about 1½ times that of the cavity area, down to equal areas according to the type of hob. In all cases a really sturdy design was used, obviating shoulders wherever possible, and blending the hobbing portion back into the section increase.

It was very important to ensure accurate centering of the hob on the slug before starting penetration, and often guides were made to facilitate this. These were usually for this purpose only and were not used during the making of full depth of the cavity.

After trying innumerable lubricants the conclusion was reached that copper was the best for general purposes. All our hobs and slug surfaces were highly polished, however, and, of course, the hobs were invariably at hardnesses in excess of 62 R_C and as free from retained austenite as possible, as it was found very early that this was a most important factor.

As far as deep cavity hobbing was concerned only two types of slug material were used, 0·07 max. straight carbon type, and 0·03C–5·00Cr–0·50Mo–0·50%V. The latter was especially good in plastic properties as well as being an interesting material from the point of view of its comparatively high core strength (about 80 tons) when used as an air-hardening case-hardening steel; but shallow cavities were made in many other types of steel including nickel and nickel chrome types.

I am very interested in what Mr Morgan has to say about the punch pressures which have to be met and the types of tool steel which he has used. I suppose that the tendency will be for even higher pressures and higher strength tool steels to be employed as the process becomes more generally used.

In our hobbing we considered that 180 tons/in^2 on the hob was the safe limit for hobs made of the type of steel mentioned (2·0C–12·0Cr) when at 62 R_C minimum. This would seem to be fairly well in accordance with the figures usually given for the compressive strength of this type of steel at this hardness, around 210 tons, which might represent a proof stress of perhaps 180 tons, or slightly better, under the most favourable conditions of treatment and prior structure. Sometimes, however, we have transmitted hobbing loads well in excess of 200 tons/in^2 through punches made from this type of material at a hardness of 64/66 R_C. However, the heterogeneity of structure often found in this steel would rather suggest the likelihood of variable results from punches in service, particularly when used in the higher hardness ranges.

High-speed steels would appear to be more suitable, with a

possible ultimate compressive strength of about 250 tons/in² and perhaps a proof stress of 225 tons/in². I am rather surprised that Mr Morgan did not have much success with them, but, as he suggests, this may have been due to press inaccuracies.

I would think that perhaps the molybdenum type high-speed steels with their tendency to good structure uniformity and satisfactory response to heat-treatment might prove a very satisfactory answer to the problem, especially where very high hardness was required. In any event, in view of the desirability of achieving the lowest possible level of retained austenite in the working structure I should certainly prefer tool steels capable of being tempered at high tempering temperatures to any others. Until recently it has not been at all easy to assess the suitability of hardened tool steels for operations such as this by any definite measurement of properties. I think that the bend test developed by Hoyle and Ineson of BISRA ought to be very helpful, not only from the standpoint of the 'quality' rating which they use to summarize the combination of properties, but also as a very good guide as to the extent to which austenite has in fact been transformed in the heat-treatment process. This test only applies to tool steels hardened into the range above about 760 DPN (60 R_C), but this is the range in which this type of information is most necessary, and it might, for example, be very interesting to obtain a bend test assessment of the properties of punches which have done particularly well, and particularly badly.

As Mr Morgan points out the success of the extrusion process largely depends on the life of the punch, and consistency of performance of punches must depend on a low level of stress raisers which may be non-uniformities of surface or structure, the exclusion of which clearly demands very high standards of material quality and punch preparation followed by optimum heat-treatment to achieve maximum wearing properties at adequate toughness.

Mr **Morgan,** in reply: With regard to tool steels, the type found to be very suitable is a high silicon steel, of which the very first punch used did 50% more components than the previous high-carbon high-chrome steels used. Although this steel does not polish up quite so well as a high-carbon high-chrome steel it has been found to be very suitable and further experiments are being made.

Because high-carbon high-chrome steels were unreliable for punches, high-speed steels are being used again. During trials the presses were not accurate at rest and they became more inaccurate under load. Therefore a very accurate sub-tool press set was built which should be independent of press inaccuracies; this was fitted with a normal die and a semi-high-speed steel punch. The punch has already produced more than twice as many components as the maximum from any previous high-carbon high-chrome steel punch and it seems clear from this that semi-high-speed steels are very suitable for punches. I agree with Mr Taylor-Gill in this regard. It must be borne in mind, however, that if cold extrusion is to be a success at least 20000 pieces per punch must be achieved as an average. Only 8000–10000 pieces were obtained even with the best punch when using the high-carbon high-chrome steels. Previously 400 pieces were made using high-speed steel for punches, but now, using the very accurate sub-tool press set and semi-high-speed steel, 20000 pieces have been made with the first punch and this is still working.

In the USA it appears from the published literature that figures of 50000 and 60000 pieces per punch are not exceptional. One can imagine that these US presses are all run using automatic feeders. In these circumstances it is essential for the press to work continuously without breakdown of the tools. Such a press would then run for eight or ten, or even more, strokes per minute, and the cost per piece would then be very low.

However, in our trial work punches in high-carbon high-chrome steel have been very unreliable, and some have fractured after making 200 pieces. The next punch might run to 7000 pieces and the next to only 100 or so. Thus, although I have quoted figures of 7000, 8000, 9000, 12000, and now with semi-high-speed steel, 20000 pieces per punch, it must be realized that these figures have been achieved but not continuously. Only recently, with the new sub-tool press set and all inaccuracies in applying the load reduced to the absolute minimum, has successful mass production been considered.

There is no trouble whatever with the dies. 40000–50000 pieces can be achieved quite easily with a steel die and I would not be surprised at obtaining 150000 pieces per die. If tungsten-carbide dies are used then stronger shrouds or shrink rings are required. The life of a tungsten-carbide die could quite easily be 250000 pieces. We are also going in for tungsten-carbide punches. Tungsten carbide has a Young's modulus about three times that of steel, and, therefore, the column strength of a tungsten-carbide punch would be much better for producing deep tubular components.

In this paper I have quoted that when using a steel punch a hole no deeper than $2\frac{1}{2}$ times the diameter of the punch can be obtained with reasonable accuracy. The Americans talk of guiding their punch through a guide sleeve and say that by so doing they achieve an accurate hole in an extrusion which can have a depth of five times the diameter of the punch. It may be possible, but we have not found it so. If the guide sleeve is to give suitable support to the punch it must do so while both the punch and die are under load. As both tools expand under load such support does not appear to be practicable. Furthermore the use of a guide sleeve increases the effective length of the punch and consequently reduces its column strength. Tungsten-carbide punches raise problems which have still to be solved, but by solving them deeper extrusions with greater accuracy and a longer tool life should be obtained.

The manufacture of flanges on bar stock is comparatively easy. The diameter of bar stock employed is usually equivalent to the diameter of the shank. The flange is then upset cold. With the tooling which has been developed the material is never allowed to go free and by this means the bar stock can be upset to $1\frac{1}{2}$–2 times its original diameter without peripheral splits occurring. Special material is not necessary for this operation; ordinary hot-rolled mild steel bar stock can be employed. This procedure has been shown to interested firms and some very good examples of components produced by this method have been seen.

The gear blanks which we have made involved three operations from the billet. These were (*a*) pierce billet, (*b*) remove base, (*c*) forward extrude. Close volumetric analysis was made to obtain a component from operation (*a*) which required the minimum disturbance of the material during the operation (*c*). By this means the press tonnage required for operation (*c*) was reduced to a minimum. The top tool employed in operation (*c*) was a simple punch in the centre of which was a splined pilot which entered the hole in the component. As the material was forward extruded into the die, therefore, it also flowed into the splines in the pilot of the punch. The correct tooth form and splined hole were, fortunately, obtained in the first set up. The gear tooth form is obviously a reproduction of the die form under load and may be exact to requirements. On the other hand it may be considered reasonable to expect a little difference between the performance of different dies and to allow for a shaving operation to finally finish the gear tooth to form and size.

Therefore, the cold extrusion of such shapes as these is comparatively simple. The tools are reasonably simple to design and easy to make. A die and a solid top tool are required. In these circumstances we do not call the top tool a punch as in our work a punch is a tool which either pierces the component or enters a hole in the component.

We are following up this work by making a new set up where the extrusion die can be swung around a central column. When in position (*a*) the extrusion die would be used to backward extrude a hollow component; when in position (*b*) the extrusion die, with the component therein, would be positioned over a hole in the press bed and the extrusion die would then become a draw die. If this set up works to plan a very simple arrangement will be possible.

We have found that the presses we use are inaccurate when tested under load, and a lot more attention has to be paid to the presses bought if they are for cold extrusion. There must be some sort of accurate guarantee under stressing or straining conditions of the press.

There are many thoughts about the question of hydraulic *v.* mechanical presses. We prefer hydraulic presses because after years of use the gibs and the main bearings of our mechanical presses have worn and the pressure of extrusion tends to tilt the ram. If this occurs during the extrusion stroke the result is to bend or shatter the punch which by that time is fixed rigidly to the ram and also held firmly in the component.

In mechanical presses there is always a tendency for the ram to throw over, by the amount of the clearance between the guiding surfaces of the ram and the gib, when the press comes over bottom dead centre, and this is detrimental to tool life. However, this tendency can be overcome if a subsidiary ram is coupled to the main ram by a double knuckled connecting rod. I know of no mechanical press with this feature, but I offer the idea to the press manufacturers to consider.

Mr **F. Rodgers** (Hadfields Ltd): The steel industry has two responsibilities in this matter: first, the supply of material to be cold forged or cold extruded; and secondly, the supply of suitable tools.

First, I would like to deal with the tools. Mr Morgan has mentioned prestressing of the liner by means of a composite form of container construction. This device, of course, has been used for many years in hot extrusion and in certain high-pressure vessels. I suggest that possibly Mr Morgan's appreciation or estimate of the radial pressure may be rather high. In most hot applications certain assumptions have to be made in the determination of the dimensions of the composite component or container, and very little information is available to enable us to determine whether or not our suppositions are correct. I would like to suggest that Mr Morgan gives us some indication of the actual strain of the outside of the container that would enable us to work back, and thus obtain some fairly precise indication of the radial pressure.

In the case of the cold extrusion of aluminium, the radial pressure is about 60% of the specific pressure. I should expect it to be rather lower in the case of steel.

In the diagrams presented in the paper the author shows two types of construction, one in which the die or liner is tapered, and the other in which it is parallel. Has he found any difference in the performance of the two constructions? The photo-elastic diagrams were most interesting and, I think, provide the answer to the abnormal spreading that Mr Morgan has found in his punches.

Regarding the ability of the various steels to withstand the stressing conditions: the author has presented a very real problem concerning the punch. Almost anything can be done with steel in respect of its mechanical properties, its corrosion resistance, heat resistance, and so on, but one vital factor over which there is no control whatever is the Young's modulus. A rough calculation made shows that if dealing with stresses of about 130 tons/in^2 strains of the order of 1% must be contended with, which is quite a problem.

Mr Morgan has mentioned the life of dies or liners. In that connexion, I would like to know which he considers to be the predominant factor that we have to face. Is it stress, or is it wear? In certain respects the two are diametrically opposed in the selection of the steel.

Coming now to the material for the application of the process, again the steel industry has some responsibility. The author's remarks concerning old iron have been taken well to heart. A review of the international literature on this subject shows that there is widely varying opinion. Some people say that steel is required in which the grain size is controlled, some say that it should be taken as rolled, and others say that it should be normalized or spheroidized.

Obviously, during the course of the extensive experimental work in which the author's establishment has been engaged, he must have gone thoroughly into these various aspects.

My final point concerns the question of extruding at intermediate temperatures. From the previous literature, we have gathered that one of the problems associated with cold extrusion is that due to the temperature increase on account of the release of energy concomitant with the process; one tends to heat the actual workpiece into the blue brittle range. Obviously, the higher the starting temperature, the greater the danger.

During the course of his experimental work, has the author attempted to cold extrude austenitic steels?

Mr **Morgan**: I admitted that the estimate for the loads on the liner was high. Obviously we started with certain assumptions. First, the practice was to always take load stroke diagrams on the presses and, therefore, always know what was the maximum load on the punch; and by analysing the total load against the area, the load per in^2 could be calculated. Without exception, based upon about a 50% reduction of cross-sectional area of component, about a 120 tons/in^2 load taken from the total load was always obtained, divided by the cross-sectional area of the punch on the punch. Up to 60%, a 150 tons/in^2 will probably be got, so we always keep to 120 tons/in^2 with about a 50% reduction of the cross-sectional area of the component.

Some dies cracked, and so we started to analyse the results on the basis of the pressure being a hydrostatic pressure and the material being completely fluid. On that basis, in accordance with a strict examination and calculation based on Larne's theorem, it was known that 130 tons/in^2 on the inner face of the liner would be obtained. Then we designed to offset that tensile hoop-stress in the liner and put in shrink rings to put about 70 tons compressive hoop-stress back into the liner at that point. The dies have been made on that basis ever since.

However, proceeding on that basis and with various dies and components produced to different shapes and sizes, when we analysed the extreme diameter of the component we were struck by the remarkable difference between a 0·010 in. strain/in., which is expected with 136 tons/in^2, and the actual diameter of the component as it comes out of the die. Some components were anything from 0·002 in. to, say, 0·005 in. or 0·006 in. bigger than the die size. Therefore, we had to find out why this was.

Obviously, when a component is extruded it gains in temperature and goes up to 200 or 250°C. Therefore, it contracts afterwards and by the time it is measured, it is cold. Therefore, probably about 0·0025 per in. of diameter of contraction on cooling must be allowed.

That still did not explain the vast difference between about 0·010 in./in. and the size obtained. At the moment the only explanation offered, which is no more than a theory, is the fact that as the extrusion is proceeding the component itself becomes part of the die in reducing the hoop stress. The punch comes down, and applies 120 tons/in^2 on the bottom of the component. It is known that the walls of the component at that stage are probably also having a radial pressure of 120 tons/in^2. The reactional forces are not always normal to the die diameter. At the bottom of the extrusion they are then almost normal to the die.

The direction of the reactional forces on the die changes as extrusion proceeds. At the commencement of extrusion the direction is about 60° to the normal to the die face, and at the end of the extrusion it is about 15° to the normal. Where the base thickness is very thin the reactional force is, for all practical purposes, normal to the die face. It will be seen from this that the component of the extrusion force acting on the face of the die, changes, and as a result the dies expand under load more at the bottom of the extrusion stroke. The extrusion load is acting on the material being extruded. Up to date we have considered that this load also acts on the inner face of the die, but examination of the size of components produced seems to indicate that the component becomes an inner ring of the die, thus reducing the tensile hoop stress on the inner face of the die to about 80/in^2.

The next question is the type of die construction, i.e.

tapered or parallel die liners. Continental practice favours tapered die liners and we started off that way. Die failures were found which could possibly have been caused by imperfect die design. The difficulty of making exactly matching tapers was a probable cause and for that reason parallel liners have been used ever since. Tapered liners make counteraction of die wear possible and some dies have been made to this design to obtain information on this point.

Although the paper states that certain dies are made of two pieces we now always make dies of three pieces, namely, a liner and two shrink rings.

It is difficult to state the life of liners as they suffer so many reversals of stress. Some liners have cracked after about 30000–40000 pieces. This is due to the continuous reversal of stress. It might be possible to counteract that by taking out the liners and warming them up, even in hot water.

Liners, of course, tend to wear, and the liners have been discarded for two reasons: because of cracking after 30000–40000 pieces, and because of wear. Some liners have maintained size after 60000 components, and a much higher figure than 30000–40000 pieces per die is required. No doubt tungsten carbide will give the answer.

Grain size in the billet has been considered from the standpoint of what is the best practice and I think it is six and two threes—whether one normalizes or spheroidizes. We always use an aluminium killed steel of about 0·15%C and subcritically anneal before use. I know that certain firms use a normalized structure; it is possible that the grain size can be controlled better by normalizing but the grain size can still be controlled even with subcritical annealing. The original austenitic grain size is known and we also know what it might be after carrying out subcritical annealing.

Much work has been done on common mild steel. For armament manufacture only the best is used. Therefore an aluminium killed steel is used so that as far as possible the possibility of strain-age hardening is reduced. However, some considerable work on extrusion of the common grades of mild steel has been done and there is no reason why one should not have a mild steel which is not aluminium killed.

Mr Rodgers made some remarks about entering the blue brittle range. Some interesting remarks concerning that were made by Dr Wilson, of the Department of Metallurgy at Birmingham, and some work carried out by Feldman, in Germany, in 1953 was most informative. It gave various graphs showing that depending on the rate of straining, the blue brittle range moves backwards to about 500°C. That is at a 600% strain range.

In normal backward extrusion of a hollow component the external diameter surface lengthens about 100%. That is to say, a billet of 1 in. length is formed into a hollow component about 2 in. long. The base of the billet hardly moves at all, but the portion of the top surface of the billet which comes directly under the punch extends up to 700%. Therefore, we are not by any means at the top limit of a strain rate of pattern which is referred to in Dr Wilson's paper on the work carried out by Feldman. Nevertheless, the blue brittle range moves backwards in accordance with the strain rate.

Referring to the question of the blue brittle range, Fig.25 in my paper illustrates three components, A.1, B.1, and C.2 which were all produced from billets at different temperatures. Component C.2 which took the lightest load to produce was, in fact, the hardest of the three components. Therefore, it appears to have entered the blue brittle range. Strain ageing is, however, time dependent and in my view this phenomena occurs after extrusion has been completed. In answer to Mr Rodgers I would say that there is a slight danger of entering the blue brittle range, but it is very slight indeed.

We have not attempted any extrusion of austenitic steels.

Mr **R. V. Rowles** (Fielding and Platt Ltd): Mr Morgan's comments on the mechanical press having the advantage in the number of strokes per minute, and power considerations, should be related to the advancement made recently in hydraulic presses. The rate of stroking of the mechanical press is usually given as the figure at which it will run continuously, whereas the operating rate is often much less, due to the time necessary to feed and remove the material. Moreover, hydraulic presses, suitable for much of the work mentioned in the paper, are known to be operating at the rate of at least 15–20 strokes per minute.

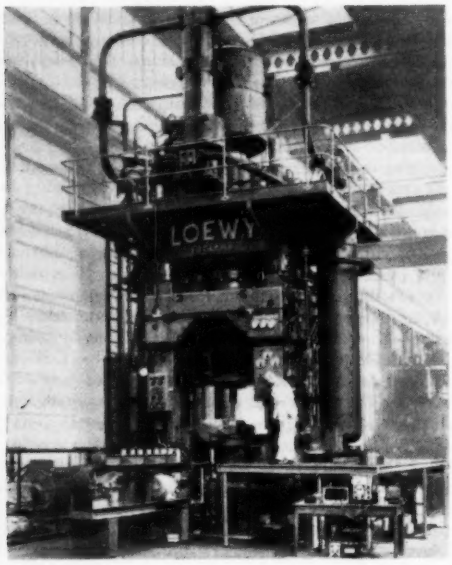
Regarding the power considerations where the load diagram is of the type shown in Fig.17 of the paper, i.e. showing a rapid build-up of power at the moment of impact to near the maximum and then flattening out during the extrusion stroke, surely the hydraulic press is the more suitable for this application, and much of the work referred to falls within this category. Hydraulic presses are working at ram speeds exceeding 25 in./s, and a great advantage of the hydraulic press is that its ram speed can be adjusted to suit the work by using suitable pump and accumulator equipment. A point I should like to make in regard to relatively high ram or punch velocities is that, although it may sound anomalous, it has been found in certain cases that an appreciable increase in punch velocity reduces the punch loading, and this is due to the greater heat generated thereby in the initially cold material due to work done during the extrusion or forming process. Of course, on this problem I subscribe most heartily to Mr Morgan's view that presses of a special type, whether mechanical or hydraulic, are necessary for this process. But I would submit that one of the crucial problems to be overcome is the challenge to metallurgists who are faced with the necessity of trying to retain uniformity of size during the length of an extrusion where the punch and die assembly is subjected to widely fluctuating heavy stresses and reversals. So how the metallurgists are going to overcome the effect of Young's modulus is a problem to which perhaps they will be able to apply themselves; and I was glad to hear Mr Rodgers touch on that point.

Reverting to the comparison between the two types of press; when the load diagram is such that the power required increases materially during the stroke, at times culminating in a coining operation, i.e. the load curve going up rapidly towards the end of the stroke, then the mechanical press has a suitable application. But, as its harmonic motion causes the punch speed to be reduced from the moment of impact, this sometimes creates premature work-hardening when the operation requires a more constant flow. In such cases it is preferable to use the hydraulic press which keeps the metal flowing at a relatively uniform rate and the desired degree of work-hardening can be obtained by adjusting the speed of the punch.

It may be of interest to mention two cases of comparison of the hydraulic press with the mechanical type. The material was non-ferrous, but the modes of flow are generally common, unless, of course, one runs into undue work-hardening with steel. First, using forward extrusion, work requiring a 1000-ton double-geared mechanical press, the same as that referred to in the paper, was also done on a special type of hydraulic press having a static rating of 250 tons and with an equivalent rate of production. I mention particularly static rating because that does not give a full answer to the energy given out by a high-speed hydraulic press. With the hydraulic press it was also possible to use a slug of double the length, because the press was able to maintain the speed throughout, and in consequence the length of extrusion was twice that achieved with the mechanical press. Secondly, a solid-ended component which could not be fully formed with a 500-ton mechanical press was completed satisfactorily with a special type of hydraulic press of 200 tons capacity.

However, the mechanical press will continue to be suitable for certain applications as each type has its field depending on the range of work to be performed. This needs to be studied very carefully.

Finally, I feel bound to join issue with Mr Morgan when he says that suitable plant that is automatic in sequence has not been designed for this type of work. There are manufacturers in this country who are anxious to accept the challenge if they are given the opportunity, and can demonstrate the commercial exploitation of its use.



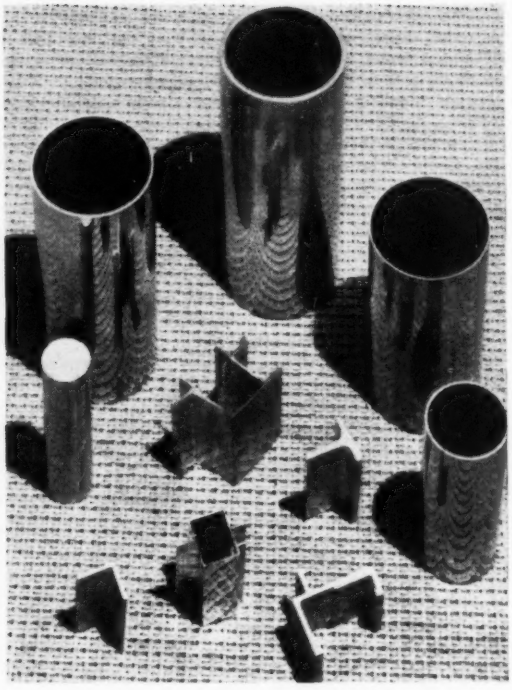
G *A 1500-ton press built to specification*

Mr **Morgan** (in reply): We have done a lot of extrusion work, and we are engaged in aluminium alloy extrusions as well as brass extrusions, and steel. The aluminium alloy extrusions were of high-strength alloys, and these were done both on hydraulic presses and on mechanical presses. I must say frankly and straightforwardly that most of the mechanical presses that we have are not really suitable for extrusion work, and although we started on mechanical presses because they were available, we have gradually tended to go over to hydraulic presses. Therefore our designers will generally prefer to put in a hydraulic press. As Mr Rowles very rightly said, a hydraulic press does not have a harmonic motion, and therefore will follow up the extrusion at the rate at which the metal goes.

We have also done extrusions on drop stamp presses and set up a component on a drop stamp press to see what would happen with a certain rate of changed momentum. Whereas on a mechanical press or a hydraulic press there was great difficulty in moving the metal beyond the base thickness equal to the wall thickness, on the drop stamp press some brown paper was put between the billet and the bottom of the die and a complete hollow tube without a base was made. The shear fault which occurs at the end of the component went up the side walls so a component with a bad end to it was still produced. Of course it was impossible to measure the exact loads imposed upon any particular component and anyway it was only an experiment to see whether drop stamps could be employed.

Obviously hydraulic presses are preferable, but at the same time, mechanical presses must not be discounted, particularly for certain operations. It is quite true, of course, that a mechanical press has to be sized up quite a bit when considering the fact that one is going to put 120 tons/in² on the punch fairly soon after extrusion, in other words, possibly in the first $\frac{1}{4}$ in.

I would not like to enter this field objectively but rather leave that to your own knowledge of presses. Generally speaking the work which we have done has been done on hydraulic presses because we can measure the loads hydraulically without going in for strain gauges which would have to be done on a mechanical press. On a mechanical press one would have to strain gauge the columns to find out what happens. We have done this on 2000-ton mechanical presses, but the big components shown in Fig.39 were done on 2500-ton hydraulic presses which were amply suitable for that class of work. The type of press used really depends upon the press range available.



H *Extrusions experimentally produced during workshop tests*

Mr **R. M. L. Elkan** (Loewy Engineering Co.): On page 293 of the paper it is stated that the deflection of the press bed under a maximum central load of 500 tons should be limited to 0·002 in.; this is a very stiff press indeed, as the local elastic deformations, and the deflection due to shear, not to mention any bending deflection, can very soon mount up to 0·002 in.

On the question of mechanical *v.* hydraulic presses for this type of work, one wonders whether on the longer strokes the consistent squeezes of a hydraulic press may not be more desirable, coupled with the ability, as already mentioned by Mr Rowles, of altering and maintaining the extrusion speed.

Mr Morgan has carried out a lot of investigations and pioneering work in this field, and I would like to ask whether, in view of his rather unique experience, he can give us his views on:

(i) the relationship for different materials between extrusion ratios, specific pressure requirements, and extrusion speeds,
(ii) apart from the higher specific pressures required for the cold extrusion of steel and the problem of lubrication, how does this process differ fundamentally from the cold extrusion of aluminium?
(iii) how should a press for the cold extrusion of steel differ from one for aluminium?
(iv) what are desirable extrusion speeds?

The question of tooling accuracy is a vital one, but one which also affects initial press costs. If great accuracy is required from the press itself, quite apart from local alignment arrangements that can be made within the tooling, then it will be much more expensive than another one, where it is possible to rely on column guiding, be this a two column or a four-column press. The latter types are very much simpler than those which have to conform to the most rigid requirements which certain customers lay down; it would be interesting to have Mr Morgan's views on press specifications.

Figure G shows a 1500-ton press which was recently built to a customer's rigid specification concerning alignment and guidance within the press. This type of machine is clearly more costly than if guiding on columns is acceptable. It has

many special features, thus providing for the possibility of extruding with extremely high speeds, and it is laid out for a high production rate per unit of time.

Figure H shows some extrusions that were experimentally produced during workshop tests.

Mr **Morgan** (in reply): I am afraid that I cannot give much information with regard to extrusion speeds. It has always been about 6 in./s simply because we have presses of that characteristic. It is possible, of course, to go at much higher speeds than that. As has been well illustrated by other authors' papers, the higher the speed of extrusion the higher the temperature increase in the component. Of course, there is a certain amount of re-crystallization and other things going on in accordance with that; so that one has to judge the extrusion speed with regard to the material to be extruded and what is going to be its characteristic afterwards.

It has to be remembered that with extrusion, taking ordinary hollow components, a component comes out at 200–250 C. That is by no means the temperature of the tool doing the work, as this might be anything up to 400 C or 500 C. The consequence is that higher extrusion speeds might be damaging to the punches or tools so I would not like to say what are the highest practicable extrusion speeds. The extrusion speed which is possible is that which will do the job and continue to do it, and it is a tie-up between work done by all sorts of people who will eventually get round the table and finally decide what are reasonable extrusion speeds for various types of material.

With regard to press bed deflection, I know from painful experience that it is easy to be deluded. Usually it is necessary to have a hole through the press bed to accommodate an extractor, and a very robust pressure pad has to be placed above this hole if deflection is to be reduced to satisfactory proportions. There should be insistence upon a deflection of no more than 0·002 in. at the centre of the bed under full load of the press.

Written contribution

Mr **R. F. Drysdale** (The Walterisation Co. Ltd) wrote: With reference to Mr Morgan's statement that phosphate coating weights in excess of 2000 mg/ft² had not proved beneficial, I agree that heavier coating weights do not show any advantage over those about 2000 mg/ft², this has been found in tests made on the components produced at ROF Birtley. However, on other examples of production of components by cold extrusion of which I have knowledge, coating weights in excess of this figure have proved to be extremely beneficial. In some cases coating weights of 3000 mg/ft² have proved to be most satisfactory, while in one case it has proved advantageous to increase the coating weight to over 4000 mg/ft². My opinion is that there is an optimum coating weight for any particular application, and that this optimum weight will depend on the percentage deformation to be achieved, the physical and chemical characteristics of the slug to be extruded, and upon the characteristics of the press employed.

Mr Taylor-Gill stated that in attempting to produce deep recesses in cold hobbing operations he had found that pick-up occurred which eventually resulted in tearing the nose off the punch. He also said that various types of lubrication, not including any phosphating, had been tried unsuccessfully. I suggest that the general experience in cold extrusion in this country to date, indicates that the use of a phosphate coating and a soap-type lubricant would have successfully overcome the difficulty referred to.

Author's reply

Mr **Morgan** wrote: I can only repeat our experience regarding coating weights.

For the normality of work a phosphate coating weight of 2000 mg/ft² is sufficient. However, if reference is made to Fig.24 of the paper, it will be noticed that the lowest extrusion load was required with the conical nose punch until such time as the lubrication broke down, when the extrusion load rose substantially. The lubrication is a function of the effectiveness of the phosphate coating and it may be that an increase in coating weight would have deferred the breakdown of the lubrication coating. It would be interesting to do more work in this connexion.

I entirely agree with Mr Drysdale, in answer to Mr Taylor-Gill, that phosphating would have been beneficial to the cold hobbing process.

Joint discussion on hot extrusion

This discussion was based on the following papers (dates of publication in the *Journal* are given in parentheses):

- **'The extrusion of steel',** by *E. K. L. Haffner* and *J. Séjournet* (1960, **195,** June, 145–162).
- **'Some aspects of steel extrusion',** by *R. Cox, T. McHugh,* and *F. A. Kirk* (1960, **194,** April, 423–434).
- **'The extrusion of steel tubes',** by *J. R. Naden* (1959, **193,** Nov., 278–284).
- **'The extrusion of high-speed steel sections',** by *P. J. Sukolski* and *G. Hoyle* (1959, **193,** Nov., 270–277).

The discussion was preceded by a film on hot extrusion, presented by the Loewy Engineering Co. Ltd, and introduced by Mr **R. M. L. Elkan** of that firm.

Mr **G. N. Cherry** (Foundry Services International Ltd): The papers presented give a very good idea of the present position and potentialities of the extrusion process for the manufacture of steel. From what the lecturers have said, this is possibly one of the most important manufacturing methods of the future, particularly as, with low tooling cost, one can have maximum flexibility in manufacture. Apart from this one can form complicated sections from comparatively brittle materials which do not readily lend themselves to the more conventional hot-working technique.

It would seem that in one operation one may carry out an enormous ratio of deformation, i.e. the ratio of cross-sectional area of original billet to cross-sectional area of finished product, and Haffner and Séjournet mention a figure of 200:1, while the largest ratio mentioned by Sukolski and Hoyle is 54:1.

My personal interest, however, is more in the metallurgical aspect which focuses attention on the quality of the billet put into the container of the extrusion press. Mr Naden, on page 279, states: 'cast machined bars and billets . . . have been used with considerable success. This is particularly so with ingots made from high-speed steels'. However, his statement at an earlier discussion may modify this. On page 426 of their paper Cox, McHugh, and Kirk, state: 'Examination of extrusions produced from continuously cast rounds in austenitic steels showed that although the surfaces were satisfactory the cast structure had been reproduced as a 'ghost' in the extruded bar' and further on they state: 'A marked dendritic structure is not to be recommended as it will be reproduced as a 'ghost' structure in the extruded bars'.

Mr Cox and his colleagues did not specifically mention high-speed steels, but if one may read the normally accepted high-speed steel structure, into their comments they would appear to be at variance with Mr Naden.

An interesting statement appears on page 273 of Sukolski and Hoyle's paper: 'The effect of reduction on break-up of carbide network is illustrated in Figs.9 and 10.' (There has been some confusion here with Fig.12.) They continue: 'It is apparent from the structures that the homogeneity is improved by increasing the reduction, as is the case for forging and rolling.'

This brings me to my first question: is the structure of the

cast ingot of great importance, provided the extrusion rate is sufficiently high? According to Hoyle a reduction ratio of 20:1 is generally considered sufficient to eliminate all traces of cellular carbide structure by conventional hot-working techniques, for example, by forging and rolling.

To produce an acceptable 1-in. round bar by an extrusion process suitable for use in tools under the most rigorous conditions, what diameter of billet would be necessary if such a billet has a normal as-cast structure, with no heat treatment, and what size of press would be required? Could Haffner and Séjournet's maximum extrusion ratio of 35:1 for high-speed steel be exceeded? Could it possibly be that the pre-spheroidization treatment may ultimately be found not to be necessary? What would be the premium on a completely homogeneous ingot? I have in mind an ingot that would obviate the necessity for excessive reduction to break down the as-cast structure mentioned by Cox *et al.* on page 426 of their paper.

Turning to the form of such an ingot, it is surprising that round ingots cast for extrusion need to be tapered. This must be uneconomic. Presumably, some method of making a parallel-sided ingot can be found or developed.

I should like to ask to which part of the ingot mould mentioned the water-cooling was applied.

From a statement on page 276 by Sukolski and Hoyle, it would appear that short ingots which can be directly extruded would be preferable to longer ones which must be cut into billet lengths, and thus allow oxidization of the surfaces of any secondary pipe that may have happened to have formed. As to surface finish of the necessary ingots or billets, while Mr Naden is prepared to use cast ingots for some materials, he prefers machined billets for expensive materials, as do the other authors. It is, perhaps, surprising that nowadays, with modern known techniques, a suitable ingot surface cannot be achieved.

Hoyle and Ineson* state that in obtaining satisfactory modifications to the cast structure of high-speed steel 'it is still believed that the ultimate answer may lie in some modification of the freezing process'. Perhaps this can be tied in with the production of a mechanically suitable ingot, and I have every reason to believe that this is perfectly feasible.

Monsieur **Séjournet** (in reply): It has been our experience so far that the best way to get a satisfactory extruded bar is to use two operations for the deformation between ingot and extruded product. The first operation is essentially a pre-compression in a closed chamber, such as we have in a piercing press, the second operation being the extrusion proper in the extrusion press.

I am pleased to hear that changes in the methods of casting high-speed steels may well lead to improvements in the subsequent extrusion, which will facilitate further the production of bars in this material by this method, and which may eliminate the first operation mentioned above.

Mr Cherry raised the question of extrusion ratio; the required press force for any given deformation depends not only on this ratio but also on the resistance to deformation of the particular steel being extruded.

We have included in this paper the extrusion formula which I already employed years ago, and which has proved substantially satisfactory in practice. When the material has a high resistance to deformation, the extrusion ratio that can be employed is less than when easier materials are involved. For instance, with carbon steels it is possible in an extreme case to operate with an extrusion ratio of 200:1; we have done this several times. On the other hand with high-speed steel, where the resistance to deformation is very high, and the speed of extrusion is limited, and where furthermore, we cannot heat the material as much as we would like, the extrusion ratio is of necessity limited, and whereas a ratio of 54:1 may be practicable under certain conditions, it may, for others, have to have lower values.

Mr **Cox** (in reply): I have only one comment to make on the extrusion ratio since I intend to leave the question of structure to my colleagues, who may have some comments on more recent work. I would say that 1-in. dia. high-speed steel could easily be obtained from the 5-in. container or, if we had another 500 tons on the press, from the 6¼-in. container.

Mr **Naden** (in reply): Referring to Mr Cherry's query regarding my statement that cast machined bars and billets have been used with considerable success, and that this is particularly so in the case of high-speed steels, there are several reasons for specially mentioning high-speed steels.

When making products from high-speed steels by conventional forging methods, many heats are required as only a small amount of hot work can be done at each heat owing to the very restricted temperature range in which the hot work can be carried out successfully. Every time the billet is heated to the forging temperature, scaling and decarburization occur, which results in appreciable losses of valuable material. It is possible to avoid almost all the scaling and decarburization losses by using extrusion as the hot working process. When extrusions are made only one heat is usually needed and the product can be extruded to the finished hot size in one operation, and, practically speaking, at the same temperature, as the hot work is finished in a matter of seconds. It is difficult to keep to tight dimensional tolerances by extrusion, i.e. a few thousandths of an inch, but this is not serious as the final products are almost always finished by machining or grinding and an allowance is made for this.

Microscopical examinations have shown that the structures of finished products made by conventional forging methods and by extrusion are practically the same, and it is certainly true to say that those made by extrusion are, if anything, superior to the ones made by other processes.

I think the fact that scaling and decarburization losses can be avoided by extrusion, and that the hot work can be finished at the same temperature in one operation is a considerable step forward in the processing of high-speed steels.

Mr **Hoyle** (in reply): Normal structures, such as those found in any commercial ingot, will be all right for the normal amount of reduction. From my experience with a 1-in. dia. bar, we found that we could get away with it structurally from a 3½-in. dia. ingot.

Mr Cherry has asked if pre-spheroidization is necessary. It gives a reasonable as-cast structure to start with, whereas with the normal as-cast structure you will always finish with some degree of stringing.

In reply to Mr Naden's point about soundness, we find that we do get a good extrusion provided there are no exposed cavities for oxidization.

Mr **McHugh:** Replying to Mr Cherry's point on the casting of ingots for extrusion, the reason why we use a tapered ingot is that to cast parallel-sided is a difficult steelmaking problem. The ingots we made were 6-in. dia. and 36 in. long and cast in a full length, thin, water-cooled tube. This was not sufficient to prevent piping.

We think that the answer to the problem of using cast material is to use continuously cast bar. This gives long straight lengths which can be quite easily machined. One drawback is that the section is not quite round, and this causes fairly heavy losses in machining. However, we are hoping to overcome this difficulty by making certain modifications to the continuous casting plant.

Mr **Kirk** (in reply): I am in agreement with what Mr Hoyle has already said about high-speed steel and the necessary amount of reduction. In our own experience we find that a similar amount of reduction is required during extrusion to that which is normally given when other means of hot working are involved. Steelmakers today are continually being driven towards higher standards for carbide distribution in the bars produced.

The work that BISRA has been doing is therefore of especial interest, and it is certain that our own future work will include

* G. Hoyle and E. Ineson: *JISI*, 1959, **193**, Nov., 254–269.

an exploration of the methods which have been described. Pre-spheroidization has been of interest to us, particularly, as makers of high-speed steel tools. Whether or not such large carbides as produced during this process are truly detrimental has still to be established. We, therefore, look forward to hearing further results of drill-testing to ascertain the effects of the partial pre-spheroidization carried out before extrusion.

Regarding Mr Cherry's question on the effect on stainless steel extrusions of continuous cast structure, we find that with a continuous cast billet a very pronounced columnar structure is obtained that is reproduced in the bars as a 'ghost' pattern after extrusion. Normal hot working, such as hammering, appears to break up the primary grains more thoroughly. Examination of bars extruded from continuous cast 18–8 stainless steel shows, however, a normal fine-grain microstructure. There seems to be no true inherent weakness.

Mr **J. A. Swain** (Incandescent Heat Co. Ltd): The paper presented by Haffner and Séjournet pays special attention to the general advantages, economics, and design features of mains frequency heaters, while Cox *et al.* give some particulars of an extrusion plant using billet heaters of this type. Their papers make only passing reference to other heating equipment. Naden, however, preserves the balance by contributing usefully on several methods of billet heating, commenting instructively on each method presented.

All the papers appear to agree on at least two important aspects, which are that (*a*) the advent of the Ugine-Séjournet processes of glass lubrication, some 14 years ago, initiated an era of steady progress in the development of the art of steel extrusion, and (*b*) steel billets heated for extrusion should be free from scale.

There are, no doubt, many more points of agreement, but I note that one author states that: 'the ideally heated billet is one uniformly soaked for a short time at the correct temperature', while another says that for certain sections 'a cooler bore is desirable'. They both agree, however, that scale has an adverse effect upon die wear and container life, and that serious defects in the extruded product can be caused by scale on the billet surface.

It is my purpose to refer particularly to the heating of steel billets for extrusion in controlled-atmosphere furnaces.

Two types of furnace may be considered as satisfactory:

(i) direct gas-fired furnace with control over the primary combustion. In this type of furnace the primary air is preheated to about 1000°C to ensure that on partial combustion no free oxygen enters the work chamber, and to facilitate the easy attainment of high temperatures

(ii) indirect gas-fired radiant-tube furnace with a controlled atmosphere prepared in a separate generator external to the furnace.

'Equiverse' is a word synonymous with scale-free heating, which applies to a direct, gas-fired furnace with controlled atmosphere, and the following brief progress report as it applies to the extrusion industry may be of interest:

(i) following an extensive research and development programme, the Equiverse system of scale-free heating was introduced to the Joint Metallurgical Societies meeting in Europe in June 1955

(ii) in 1956 a pilot furnace was installed in northern Germany to test an automatic control system and obtain information on which to base the design of a large rotary annular hearth furnace

(iii) in 1956, a pilot furnace was installed in France for heating billets of stainless steel and various alloy and carbon steel qualities and injecting them into the production programme which was normally maintained by a preheating furnace and salt bath

(iv) early in 1957 an existing direct-fired furnace in Chesterfield was converted to the Equiverse system for heating stainless steel billets and is still in use for the production of high-quality tubes

(v) by the middle of 1957 the projected rotary hearth furnace, 10 m mean diameter with an annulus 1·5 m wide, was under test at Schwerter Profileisenwalzwerk AG, and it was reported in April 1958 that 'throughout the whole of the working period of the furnace, so far, scale-free heating has always been obtained', and this statement is as true today as it was then.

(vi) as a result of the test in France in 1956–57, and further investigations, a major Equiverse installation is now projected for Vallourec, one of the licencees of CIEPM.

The furnace converted for Chesterfield is by no means an ideal application for the Equiverse system, but performance was investigated over an eight-week period in 1957, showing an average fuel consumption of 2·5 m. Btu/ton when operating at less than half-rated capacity for two shifts out of three. The performance was based on the total gas consumed for each full five-day week, including lighting up, meal breaks, shift changes, press delays, and holding temperature during the non-productive shift. This performance is substantially better than that obtained from similar furnaces conventionally fired operating at full capacity for three shifts.

Experimental work in connexion with the extrusion process has made it virtually impossible to assess performance on the rotary hearth furnace at Schwerter Profileisenwalzwerk AG. Until recently the furnace has operated on single shift, with many delays in production and throughput, sometimes little more than 1 ton/h. It is gratifying, however, to report that even under these adverse conditions no difficulty has been experienced in maintaining pressure at hearth level and in preventing infiltration of air at the doors. Early in 1960, this furnace should be operating at an average throughput of 8 ton/h with a performance of 22 therms/ton.

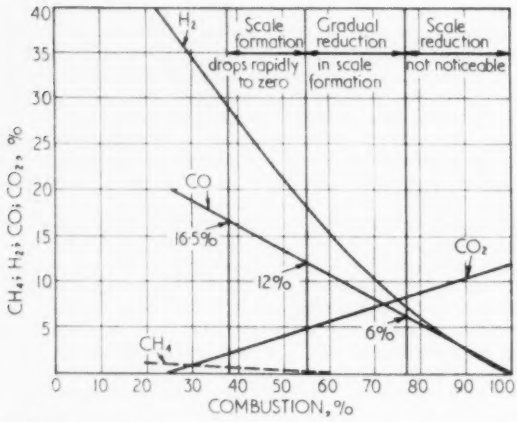
The Equiverse system of scale-free heating is completely satisfactory for heating carbon steel billets before extrusion. It is also satisfactory for heating stainless steel billets provided that the heating cycle is not too long extended to cause appreciable sub-surface chromium attack. It is desirable to heat most chromium-bearing alloys in a high-temperature gas-fired radiant-tube furnace with a specially prepared controlled atmosphere produced in a separate generator.

When heating high-speed steel in the Equiverse atmosphere it has been shown to be scale-free. Decarburization persists, however, although to a lesser extent than when heated in a conventional direct-fired furnace. It would appear, therefore, according to our present knowledge, that it would be best to use the radiant-tube furnace for heating high-speed steel billets for extrusion.

The high cost of low-frequency heating in capital expenditure and heating costs compares unfavourably with furnaces used for similar duty, but it is a convenient form of heating for intermittent usage on low production. If, as Séjournet suggests, continuous productive capacity of 20 tons/h and 40 tons/h or more is the current objective in the extrusion industry, furnace heating would seem to be the most promising proposition.

In certain cases, for metallurgical reasons as well as to ensure that the temperature gradient through the billet is not too great, the user of induction heating has to resort to recycling procedures on billets 6¼ in. dia. Nothing has been said about axial uniformity of heating. Here, I may say that it was obvious from the film shown earlier that the surface was not uniformly heated, either radially or axially. It is stated that without an inert atmosphere around the coils, temperature measurement is affected by scale, and safety precautions other than temperature control are necessary to prevent overheating.

It is my understanding that stainless steel may be preheated to a temperature of 800–900°C in a direct gas-fired furnace without atmosphere control, and that no adverse effect on the extrusion is apparent provided that the final heating is carried out in a reducing atmosphere. Carbon steel, however, can only be preheated to about 500–550°C without atmosphere protection. The temperature for preheating high-speed steel, neglecting a controlled atmosphere, may be lower



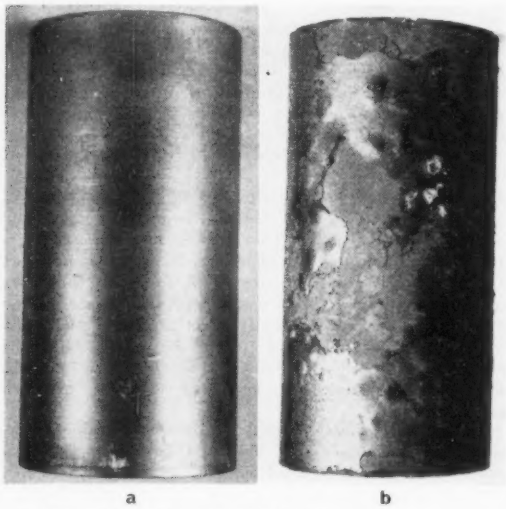
I *Relation of atmosphere in open furnaces with the oxidization of steels*

still, although appreciable decarburization does not occur at temperatures below 800–900°C. I believe that above this temperature the heating of the billet can be quite rapid.

It is obvious that heating techniques must be devised to suit the materials to be extruded. I am confident that the thermal engineer will be able to satisfy the demands of the metallurgist and extrusion engineer in this respect.

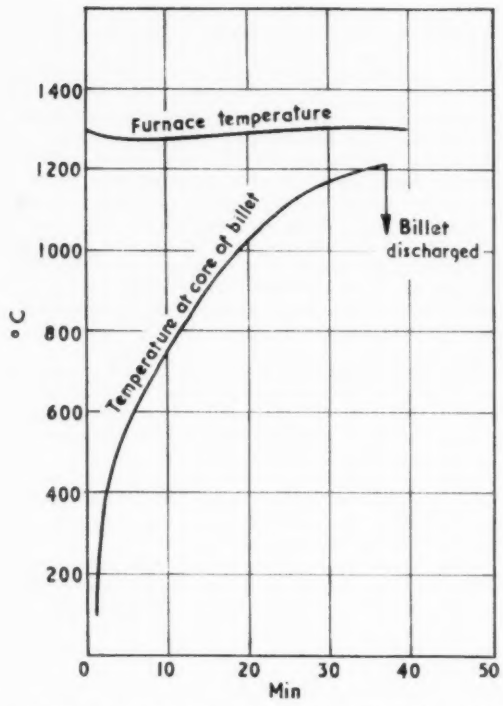
I should like to make clear what is meant by a direct gas-fired controlled-atmosphere furnace. Figure *I* illustrates the significance of Mawhinney's reference to investigations by Jominy and Murphy* which established the relation between the atmosphere in open furnaces and the oxidization or scaling of many steels. The graph has been prepared on Smethwick town gas, as it will vary according to the quality of gas available. It will be noticed that up to 6%CO in the flue gases, the reduction of scale formed in the furnace is not noticeable. From 6–12% in the flue gases, there is a gradual reduction in scale formation, and from 12–16·5% the scale formation drops rapidly to zero.

* M. H. MAWHINNEY: 'The heating of steel'; 7, 1945, New York, Reinhold.



(a) Heated in Equiverse atmosphere
(b) Heated in a direct-fired furnace

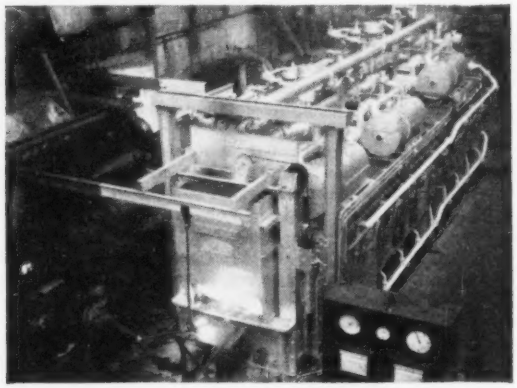
J *Identical billets after heating to 1280°C in 20 min, held at 1280°C for 30 min and cooled in dry nitrogen*



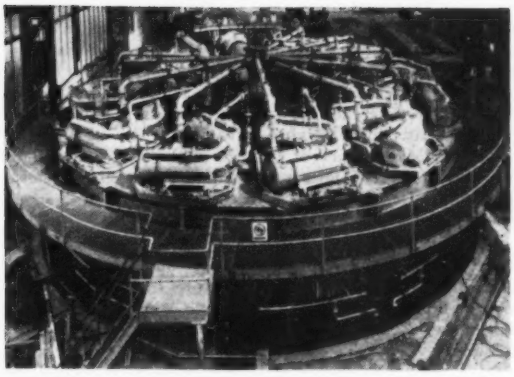
K *Heating curve for 7 in. dia.×12 in. long mild-steel billet weighing 130 lb*

Figure *J* compares two identical billets which were raised to a temperature of 1280°C in about 20 min, and held for 30 min at that temperature, after which both were cooled in dry nitrogen. The clean billet was heated in the Equiverse atmosphere, and the metal loss was found to be nil. The other billet was heated in a direct-fired gas furnace with careful control over atmosphere conditions.

Figure *K* is merely to show that heating can be quite rapid in an open-fired controlled-atmosphere furnace. Of course, only one billet was placed in a small furnace for this experiment, but it was interesting to note that the core temperature measured by means of a thermocouple located in a drilled hole with the hot junction in the middle of the billet was attained with a heating rate of only just over 5 min/in. of diameter when operating with a furnace temperature lead of only 80°C above the core temperature of 1220°C.



L *Chesterfield furnace equipped with three regenerator assemblies*



M *Schwerter rotary furnace equipped with nine regenerator assemblies*

Figure *L* shows the Chesterfield furnace which is equipped with three regenerator assemblies, although perhaps in the light of experience only two units are needed to sustain the production required.

Figure *M* shows the Schwerter rotary furnace on which nine regenerator assemblies were originally fitted. The number in use has been reduced, but if a similar furnace were constructed today only four regenerators of larger capacity would be applied.

Finally Metal Porcelains Ltd have started an investigation aimed at improving the composition of the frit used for coating billets before heating up for extrusion. It appears that, while a comparatively viscous glass is required when the billets are at a temperature of 1000°C or above, a degree of oxidization and, therefore, scaling, occurs well below this temperature during the heating-up period. It is hoped that by mixing more fluid types of glass into the powder, some of which will melt at temperatures of 300–400°C and upwards, the earlier melting of these will help to seal off the billet surface at a much lower temperature than at present.

Monsieur **Séjournet** (in reply): There is no doubt that the Equiverse system has its field of application. What we require for extrusion is a furnace which is really rapid in its heating rate, and which we can switch off in a very short period of time according to production requirements, and dependant upon the various materials that have to be extruded. Regarding uniform temperatures throughout the billet, recent measurements have shown that such uniform temperatures are required for certain applications but that a certain temperature gradient is equally important for some others. It is clear, for instance, that the centre portion of a uniformly heated billet, when extruding a finned tube, will flow very much more easily than the outside fins, and in such a case a temperature gradient is very important. We have not been able to achieve such a temperature gradient in any furnace other than by induction heating.

In the extrusion process where the die ultimately imparts the required profile such a die can be quickly changed in a very short time. The material being extruded is liable to change very frequently. These were factors which led us to the conclusion that for our production programme and purpose the induction heater was the right equipment.

It is quite right to say that there was some difficulty in achieving correct temperature control under certain circumstances, generally due to scale formation, or sometimes due to surface condition of the billet when this is not machined before insertion into the LF induction heating coil: Such early difficulties, however, have been overcome, and alternative techniques of achieving the correct extrusion temperature in the billet established.

Mr **Haffner** (in reply): I would also like to make a few comments in connexion with Mr Swain's remarks. It is quite clear that he is convinced that the Equiverse furnace is the right answer for the heating of steel billets for extrusion, and it is the system with which he is associated. I might agree that if one had a steady output of 20 tons/h or more, day in, day out, for three shifts, or two at least, then this type of furnace might be the answer for certain cases. Unfortunately, in extrusion, this situation has not occurred to date, with the variable programmes, both from the point of view of product and material encountered in extrusion press plants.

When starting up a plant, or when extruding small sections, one may produce only at the rate of, say, 2 tons/h for an hour or so. Immediately afterwards the programme may be one of heavy sections where the output may go up to a rate of 6 or 8 tons/h.

In Mr Swain's scheme a furnace capable of dealing with the maximum output must always be in operation, and in fact he mentioned one such unit operating on single shift, with many delays in production and throughput, working sometimes at little more than 1 ton/h. If this same furnace is capable of a throughput of 8 tons/h, there is inevitable wastage on the two idle shifts: This also happens when the press is working at a rate which is only one-eighth of the throughput of which it is capable. With induction heating, on the other hand, not only is there infinite flexibility from the aspect of adjustment of temperature, necessary when going from one material to another, but one can use one, two, three, or six coils depending on the installation, and according to the requirements at any one moment, i.e. one can alter the number of heaters in operation. A plant may well become uneconomical because of the extravagance of a huge furnace with which it may be saddled. With induction heaters one can operate according to requirements, and there are no power or other losses whatever when billets are not being heated.

Mr **Naden** (in reply): I am in agreement with Mr Cox about the particular eight-finned section he mentions. Variations in the billet temperature can be advantageous in such a case, but my paper was deliberately confined to tubes, and for tubes of the thicknesses usually met with in extrusion a uniformly heated billet is ideal.

I agree with Mr Swain that the Chesterfield furnace is not ideal. It was modified in the early days of the Equiverse, and the Equiverse should not be judged on the performance at Chesterfield. I also agree with him when he says that the Equiverse will heat carbon steels satisfactorily, and very good products are obtained from billets heated in this way. It is also true that the heating of stainless steel billets is satisfactory, provided they are only a short time in the high-temperature zone of the furnace.

Mr **Cox** (in reply): I would like to make one comment on something said by Mr Swain on the heating of billets. I have no axe to grind between one form of heating and another, but for some sections we have found taper heating to be essential. I do not know of any other form of heating that will give this without a lot of complications. We find taper heating essential for certain types of material, because of the temperature rise (mentioned by Mr Morgan) due to the working of the metal.

Monsieur **Séjournet** (in reply): I would also like to return to Mr Swain's comments. We all know that to get a good finish on our extrusions it is necessary to avoid scale. A considerable amount of experimental work has been done all over the world with different types of heating. It must also not be forgotten that sometimes the choice of the heating method to be adopted may be strongly influenced by the local fuel that is available. In some parts of the world there is no gas at all, in which case induction heating is the only answer.

Where there has been a choice we know of several different heating methods that have been successfully used, but they all have their disadvantages. For example, the gas-fired furnace produces a small amount of scale, another variation of this

furnace is very good but is very expensive to run, while yet another type of furnace which is working at the moment and which is well known, is the Balestra-furnace, in which molten glass is used to protect the billets; this type of furnace, however, is limited to small billets, otherwise difficulties are encountered.

At present, therefore, the two best ways of heating are the induction furnace and the gas-fired furnace with scale free heating in a controlled atmosphere. We also agree, as Mr Haffner has just stated, that induction heating is best for the production of expensive material, and there is no doubt that it has been proved to be good for extrusion. At the same time the gas-fired furnace also has some advantages, and when we utilize a controlled atmosphere type, then this sort of furnace could be applied for large capacities.

At present we extrude specialized carbon steel sections and when the day comes that we wish to extrude carbon steel tubes, we cannot think in terms of 2 or 3 tons. We have to compete with conventional production methods, and this implies thinking in terms of 20, 40, and even 60 tons/h; I doubt whether 40 tons/h is the right application for induction heating.

We have heard that the furnace in Schwerter is going well, but it has a capacity of only 8 tons/h. For our plant we are thinking of a furnace capable of heating 24 tons/h which changes the whole picture.

I agree that uniform heating is good but when special problems are encountered in extrusion, non-uniform heating may, under certain circumstances, be better and bring with it the solution to some difficult extrusion problem. Even on the large hourly production programme I have just mentioned, induction heating will still be required, certainly for the re-heating between the piercing press and the extrusion press, when making tubes, whereas before the piercing-press, gas-fired furnaces for large outputs may have been required.

Dr **J. G. Wistreich** (BISRA): I found Monsieur Séjournet's arguments about the economics of the process most interesting, and I look forward to him enlarging on the subject by way of more specific statements. In particular, would he explain Fig.2; is the curve of 'minimum production' a curve below which the extrusion process is not economical?

It is now well accepted that extrusion is the appropriate process for un-rollable sections, difficult alloys, and the small-batch production of rollable sections. At a previous discussion, however, Monsieur Séjournet made some remarks which led me to think that he was sanguine about breaking into large-tonnage production which is generally regarded as the preserve of rolling. Could he make his views more specific by giving some figures for the 'cross-over' in terms of production costs from extrusion to rolling? Further, can he give us some figures of the material yield in support of his statement on 'the metal losses in the process are smaller than for orthodox processes'. When one looks at the illustrations of the discards in extrusions, one wonders how he can claim a high yield.

As regards the future of the process, and bearing in mind Monsieur Séjournet's incomparable experience of its development, where does he feel the greatest scope and need for further development and advance is? Is it in longer die life? Does it lie in the direction of cheaper materials? By 'cheaper' I mean the substitution of cast for wrought steel.

Mr Haffner, it is clear, has made some quite remarkable advances in the speeding up of the press working cycle. How much further can one go in that direction? At first sight one would think that there must be much more scope, because the total cycle time that he envisages on new presses is, I think, of the order of 30 or 40 s and the actual extrusion takes only 2–4 s. However, a limit on a further reduction of the time between pushes is clearly imposed by the risk of overheating of tools. What is this limit, in Mr Haffner's opinion, and does he think that this could be altered by using a colder slug and relying on fast extrusion to heat it up to the optimum working temperature? Finally, how do the authors rate the prospects of multiple extrusion as a means of raising press output?

Monsieur **Séjournet** (in reply): To Dr Wistreich I would say that the minimum production curve of Fig.2 indicates the type of output that should be achievable on a mixed programme of relatively small order batches, or one which implies frequent and close inspection of dies and profile. For any press there is a considerable difference between the maximum and minimum tonnage that can be produced from it, which is largely the result of the difference of the size of the particular product being extruded, i.e. there is an extreme variation between the maximum and minimum weight per foot run that can be produced.

If a press is supposed to cover a complete range of sizes, then it will sometimes have to produce very small weights. If, however, it is loaded at all times near to its maximum capacity, say extruding heavy weights per foot run of easily extrudable material, then a very high hourly throughput will be achieved.

Concerning the question of yield, this can be quite high, and we have on occasions even extruded without discard at all. The scrap is kept down to a minimum, as are subsequent grinding and other operations. The best yield figure we have obtained on stainless steel tubes is 88% for 1000 tons, starting with bar stock in long lengths, and I doubt whether the figure for carbon steel tubing would be very different.

As for the future I think the trend will be towards the extrusion of the cheaper steels; hitherto extrusion all over the world has largely dealt with the more expensive alloy steels. So far a lot of carbon steel sections have been produced, but I think in the future extruded carbon steel tubes will also come into their own.

We shall have a new extrusion plant in France, and the first thing we shall do is to make ball bearing steel tubes which are expensive to produce by conventional methods, and require much care. I hope that the production of ball bearing tubing in the correct sizes will prove to be economical, which implies an appropriate throughput in tons/h. We have made perfectly good ball bearing tubes in the past by extrusion, the only thing that held us back was the limited tonnage we produced per hour.

I have no doubt furthermore, that we shall see presses capable of more and more extrusions per hour. Today such presses are capable, already, of 60 extrusions per hour, and on one of our older presses, we have at times even extruded at the rate of 80 per hour. What is needed, therefore, is equipment capable of higher production rates; as far as most steels are concerned the faster you extrude the better the product, and clearly the higher the production rate the more economical the process becomes. For this reason I have no fears that we shall see the development of the economical extrusion of carbon steel tubes, after which the next step will be to tackle sections in the same material, and the greater the output per unit of time the sooner we will approach competitive cost prices, even with this cheaper material. I feel sure that we will all be surprised at the development of extrusion in the years ahead.

Mr **Haffner** (in reply): With reference to Dr Wistreich's question as to how much further one can go in the speeding up of the press working cycle, I would say that some of our recent presses were laid out for a theoretical idle time of around 26–28 s, which, when one adds an extrusion time of 2–4 s would give a total cycle time in the region of 30 s, or a total of 120 extrusions per hour. This is a theoretical figure and is applied to the press as such; the plant operator would like to reach it, but as we know, there are other factors that retard the output that is achievable, e.g. the cooling of all the tools, the exchanging of mandrels, the control of dies, and so forth.

All these present vitally important secondary problems, and we have met them in our newer presses by such devices as internal mandrel cooling, push button actuated die-changing equipment, and others.

Concerning Dr Wistreich's question on whether the press cycle time can be further reduced, I would only say at this stage that we are developing new presses which will be capable of higher production rates than have hitherto been thought

possible, but it is the secondary problems of tool cooling, die control, etc., which will also have to be carefully dealt with.

Concerning the use of billets at a lower temperature, I would say that each material should be extruded at the lowest temperature possible. Unfortunately the situation that arises is that operators wish to use a small press, and achieve a big output from it, and no sooner is a press plant installed than they wish to produce sections that are very much larger than those for which the press was originally selected. Larger containers are then employed and to overcome the resulting difficulties, the billets are heated to a higher temperature. This adversely affects tool life, and the extrusion speed is lowered as the press works nearer the border line of its maximum rating; due to internal friction, further heat is added as the extrusion proceeds so that cracking and other unsatisfactory surface conditions may appear.

The ideal situation is one where a press is installed for a certain production programme right from the beginning, and is then worked at the programme for which it was intended.

Mr **F. Rodgers** (Hadfields Ltd): I would like to turn for a moment to the question of cost, and I think that this is something that rests on Mr Haffner's shoulders. So far we have spoken of the production of tubes which lend themselves particularly to extrusion methods, but in the steel industry in general it is fair to say that the bulk of companies are not interested in the production of tubes. We have, in this country, highly specialized industrial groups that are well versed in that production and have all the necessary ancillary equipment. Therefore, the steel producer who is considering the installation of a plant of this type must think of the economics of producing sections that can already be produced by conventional methods.

To be quite frank I found some of the comments and information presented in these papers rather alarming in this respect. Anybody considering a new method of production has first to convince his board of directors that there is a reasonable difference between production cost and delivery price. More important still he has to convince them that the cost difference is of the right colour!

I am not too sure that the extrusion process has much future in the production of normal steel sections. In his paper, Haffner has listed the pros and cons of extrusion *v.* rolling, but he has done so, I think, with particular reference to tubes. The special sections are certainly not required in vast quantities.

Another aspect of the cost question is yield. By the time the billet reaches the extrusion factory it has probably had a discard of about 20%, so that the yield (end product ratio as compared with the original ingot weight) is less using extrusion than using conventional methods of manufacture, such as rolling.

I want to refer to two specific points in Haffner's paper, the first relates to Fig.3. My company is interested in the supply of tools for the application of this process, and I am not quite sure what is meant by the die temperature referred to in Fig.3. Does it mean that the die temperature never exceeds 50°C?

Next, can low-frequency heating be applied to a square-section billet? I know that that is rather an awkward question, but if Mr Haffner has any experience of this can he say whether his low-frequency heating devices are used for that purpose?

Mr Naden referred to the effect of machine finishing, i.e. the finish of the billet and its effect on the extruded product. Returning to the question of cost, we were exhorted recently by our major customer, the car industry, to have two objectives in mind; to produce the highest quality steel possible, and to produce it at the lowest possible cost, with particular reference to surface quality. Mr Naden has shown us a specimen which, if presented to the car or forging industry, would, I am quite sure, result in the breakdown of negotiations with the customer.

Mr Sukolski has mentioned internal cavities. This is a subject very near to the steel industry's heart. As I see it, one feature of the extrusion process is the hot forming of some of the very recently developed complex alloy steels which do not lend themselves to conventional hot working. Extrusion has the advantage over other methods in that the work piece is fully supported during the application of the deforming forces, and the very fair claim is made by certain extrusion experts that whatever we can roll they can extrude, and, in fact, can do it better.

The future of the process is no doubt very much tied up with the ability of tools to withstand the most onerous conditions, and those companies interested in the manufacture of extrusion tools have these new requirements constantly in mind.

On ingot design, it is not a practical proposition to produce large ingots in the form of rounds by conventional methods; nor is it practicable to produce them with parallel sides. The reasons are directional solidification and the ease of stripping from the mould.

Mr **Haffner** (in reply): Commenting on Mr Rodgers' remarks, I would say that extrusion of tubes has been emphasized to a considerable extent in the paper, since they form such a big proportion of the production programmes in many plants. Clearly an extrusion plant should have some basic standard production programme with which it can achieve a high output, although this in itself does not mean that a considerable variety of sections and profiles cannot also be produced, and sold at a profitable margin, especially when they are sections that cannot be produced by rolling, owing either to material or shape, or with the versatility obtainable from an extrusion press.

An extrusion press may be built for tube extrusion, but all other sections can also be extruded from the same machine; e.g. I have seen architectural sections produced in stainless steel, which will have a big future.

Concerning Mr Rodgers' question on Fig.3, the die temperature is shown at the instant of initial contact between itself and the glass plate at the point of precompression, i.e. when the hot billet makes contact. The die temperature certainly rises into the region of 200–300°C and more under certain circumstances. Finally, low-frequency heating of square section billets presents no difficulties.

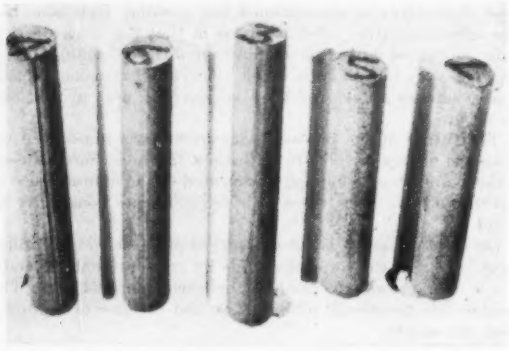
Monsieur **Séjournet** (in reply): I also would like to comment on Mr Rodgers' question concerning die temperature. This rises well in excess of 200°C once extrusion starts, and in Fig.3 we merely indicate the temperature at the beginning, and not at the end of the operation. Dies nowadays always have to be cooled, although the extrusion operation may only take 2–3 s.

Concerning operating economics, with special reference also to carbon tube manufacture, I would agree that a firm which already has tube mills would have to seriously examine the possibility of changing over to extrusion; a problem which is made very much easier for companies which have no existing equipment, and who wish to decide on which way to go.

In many countries abroad this latter situation arises, and we feel that the best way to get ahead with extrusion is to install a plant, learn to use it, and go on from there, selling the products more and more economically as you proceed.

Mr **Sukolski** (in reply): I agree with Mr Rodgers about difficult steels and the advantages to be gained from extrusion in this field. Our experiments on high-speed steels are in fact an example of this in that we could use much higher working temperatures during extrusion than would have been possible during other, at present conventional, methods of hot working. The net result was a strong indication that the resulting bars were of improved quality.

Here I would like to return to Monsieur Séjournet's comments on the extrusion of high-speed steel. Extrusion pressure is certainly a most important consideration, but the relatively high temperatures enabled us to extrude at very reasonable pressures at a ratio of 54:1, and we could see no particular difficulty in going still higher. Certainly we would consider the 35:1 mentioned for simple round bars as conservative.



N *Bars extruded with a different glass*

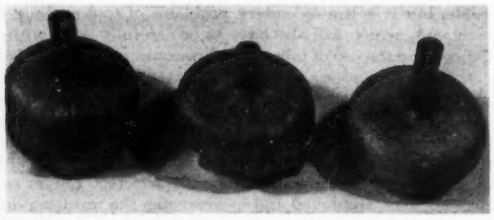
I agree with the statements by Mr Cox and his colleagues about the importance of the type of glass used as a lubricant. Our experiments at BISRA indicated that different glasses were likely to give best results with different alloys. One series of experiments was carried out extruding an 18–8, 3%Mo stainless steel with six different glass compositions. Each glass was undoubtedly not tested under its optimum conditions since, for example, the temperature of extrusion was not varied. However, temperature variations are often limited to quite a narrow range anyway as dictated by the steel being extruded, so this merely strengthens the argument. Figures *N* and *O* illustrate the results obtained. In Fig.*O* the surface of one of the discards is quite smooth, and the bar was very good. At the other extreme lines can be seen along the discard which was associated with a very poor bar.

Much has been said about glass lubrication, the importance of which, of course, is undisputed as regards hot steel extrusion. I feel, however, that more should be said about the use of solid lubricants, and I was, therefore, most interested to read Mr Naden's comments on graphitic lubrication, and I would like to add to them.

The most important property of glass with respect to the die is probably the volume in which it is retained, and its insulating properties which provide protection during extrusion. When graphitic lubrication is used, in particular with certain types of sections, other means must be found of protecting the die until, perhaps, a die material is found which can withstand the conditions. Dies for extruding sections with re-entrant portions are the most difficult to protect, particularly at the tongue which forms the re-entrant part. With relatively simple sections I have experienced most interesting results when using solid lubricants as opposed to glass.

In addition to Mr Naden's comments, the following advantages, as indicated by small-scale experiments, can be claimed for solid lubricants over glass. First, the general surface finish on some alloys tends to be of a higher standard, although some of this may have been associated with the scale on the billet, as described by Mr Naden. Secondly, sections can be produced with sharp corners, a condition not possible with glass lubrication. Thirdly, for alloys difficult to hot-work there was greater scope for variation in die design. Correct die design is most important when extruding difficult-to-work alloys, and glass lubrication imposes certain undesirable limitations. In dies designed for glass lubrication, for example, some account must be taken of glass retention, and this is not necessarily in the best interests of the metal. On the other hand, of course, with some difficult-to-work alloys, the insulating effects of the glass may be important, and the balance as to whether glass or graphitic lubricant is better probably depends on the properties of the particular material being extruded.

Finally, I would like to turn briefly to extrusion temperatures and, in particular, to so-called zones of hot shortness which have been mentioned in the paper. Hot shortness is, I feel, a very bad term, and one frequently used rather loosely, implying a temperature-dependent property only of a material.



O *Discards showing surface quality of the bars*

The tendency of any material to crack when hot worked depends very much on the method of hot working, that is, on the stress and strain conditions applied. Indeed, it is for this reason that materials difficult to roll or forge can often be extruded quite readily. In extrusion itself, however, conditions are very important, and I have found die design, for instance, to be very critical. For example, I had the experience of extruding a heat-resisting cast iron, in which, at 980°C the pressure of extrusion was too high and the billet did not extrude, whereas at and above 1020°C the bar was severely cracked. By changing the design of the die a very good bar was extruded at 1080°C, at a pressure well within the capacity of the press. The extrusion ratio was about 35:1 and graphitic lubrication was used. Also, while extruding a rectangular section with sharp corners in a hot die steel, one die's corners were badly torn but with another the bar was perfectly sound.

Thus, the so-called hot short range of the materials in the examples has been moved upwards with respect to temperature, and there is no reason why, with alterations in extrusion practice, it should not be possible in some instances to move out of danger or to increase temperatures to gain advantages with pressures and/or properties.

Mr **Cox:** Monsieur Séjournet and his colleagues and I will argue about solid section extrusion for years, but I am convinced that the rates of extrusion quoted apply today, and will apply in future, to tube extrusion only. For some of the sections we have illustrated, such high rates and tonnages are completely out of the question. I do not think that it is intended that the extrusion press at present is taking the place of the rolling mill. We certainly could not compete in the manufacture of round mild steel and carbon steel bars. Only when we get something out of the ordinary can we compete satisfactorily, and when this sort of section comes along the production rates are rather low.

Then there are the square billets in round holes. We have heated, in the induction heater ordinarily used for rounds, 18–8 square billets, which would normally have gone to our rolling mill. We have extruded them into ¾-in. dia. bars with reasonable results. The surface finish has not been as good as with a round billet turned in the normal way. The billet was ground as it would be in the ordinary course of manufacture for the rolling mill.

We stated in our paper that we normally started with a die temperature of about 200°C. We have not really taken any checks during the whole of the course of the extrusion, but we know that some of our 8-finned tube dies have been at least 700–800°C because they have been red hot at the tip towards the end of the day after a long run of extrusion. We take the precaution of cooling down with a blast of compressed air. It is usual on a long run to have as many dies as you can to allow for cooling to a satisfactory temperature.

Mr **D. Lacy-Hulbert** (The Chesterfield Tube Co.): Extrusion falls naturally into three main groups: stainless tubes and sections, ferritic steel sections, and ferritic tubes. It is, of course, possible to make all three on one plant if adequate finishing equipment is provided; and much will depend upon the state of the order book. When stainless steel was originally made, great difficulty was experienced in making tubes, and the use of hydraulic extrusion provided the first break-through.

It is not known whether this started in Germany or at Chesterfield. The fact was established that a method that was economically successful had been evolved; this was in the early 1930's and oil and graphite were the lubricants. The advent of glass as a lubricant gave the process a new look and made possible the extrusion of thinner and longer tubes.

To gain these advantages, special billet heating furnaces and ancillary plant are needed, which differ greatly from the early plant installed at Chesterfield. Such special plant is of large capital cost, while conversion charges are still relatively high owing to the need for smooth surface billets, radiused in many cases, high tool costs, and specially trained supervision. Despite these disadvantages, however, it is my opinion that there is no better way of making stainless tubes, but there is much room for cost reductions.

Regarding solid sections, I thoroughly endorse all Mr Cox's remarks. The economics of solid extrusions are not at all clear. It appears that in France, Germany, and Italy the process thrives, while in Great Britain the economics are not attractive, and a plant put in specially for this purpose in the USA has, I understand, been closed down. Could the problem be related to the complexity of sections called for in the respective countries, and the ability of the many hot rollers, certainly in this country, to supply simple sections at a very low price?

The question of extruding plain carbon steel tubes is particularly interesting. In general the conventional tube making processes have been used and developed since the beginning of the century. Glass extrusion, on the other hand, is effectively about ten years old, and is, therefore, comparatively young. Can it be that in a further 10 or 20 years the gap in conversion costs will so be narrowed that extrusion will start to compete with, and take the place of, some of the conventional methods?

We have heard of the possibility of presses operating at 100 to 110 extrusions per hour and converting up to 24 tons/h into tubes. Should such prove practicable and should sufficient improvements result from research and development, then I believe extrusion will break into the preserves of some of the long established tube making techniques.

Written contributions

Mr **R. M. L. Elkan** (The Loewy Engineering Co. Ltd) wrote: We have heard a great deal about the problem of the heating of steel billets for extrusion. This is puzzling, for with induction heating, and it should be recalled that some 80 or so steel billet heater units will soon be in operation all over the world, the problem of heating has been removed.

In hundreds of test readings made, it has been established that heat patterns, having the billet core cooler, hotter, or virtually identical with the temperature at the billet surface, can be arranged for with low-frequency induction heating, provided that the equipment is correctly installed and set in the first place. When it is realized, however, that in the first 20 or 30 s after the billet has left the induction heater, or indeed any other furnace, its surface loses some 100°C or so in temperature, then one quickly comes to the conclusion that the unsolved problem is not in the heating at all, but in the handling after heating, i.e. between furnaces and the piercing and extrusion presses.

There has been a great deal said on uniform billet heating and the absence of scale formation during heating. Nobody can deny that these requirements have been met to that degree which is required in practice, by low-frequency induction heating, but a lot of the technical achievement in the latter heating method can be nullified by what then happens to the billet when it has left the heater, in terms of scale formation and temperature drop, until extrusion finally begins in the container of the extrusion press.

It must not be forgotten that with low-frequency induction heating, not only can radial temperature patterns be catered for, but similar patterns can be achieved in the axial direction.

Mr Cox would be the last to deny that his press is being used on work more appropriate to a larger unit, for the extrusion temperatures quoted are high. He would also agree I am sure, that better die, mandrel, and liner lives than those he quotes could be achieved, if lower extrusion temperatures and higher extrusion speeds were available. This implies higher specific pressures, i.e. a larger press for the same conditions. It is easy to see from the paper that the press and the induction heating equipment are effectively employed.

Mr Cox emphasizes the need for immediate glassing as the billet emerges from the coil, to eliminate the danger of scale formation between heaters and press. This precaution would seem to be especially important; for instance, also in the case of carbon steels.

The desirability of having as high an extrusion speed as possible, as this has been found to produce the most consistent sections, is also mentioned. High speeds at a high proportion of press tonnage, however, have to be paid for when the plant is originally laid down. A high circuit efficiency implies a large initial outlay. When people buy a 50 hp motor, they regard it as normal that this hp is available at the shaft, not at the power station. It is surprising how long engineers have rated their presses effectively at the accumulator station, instead of in the container, where the metal is being deformed. However, the effective utilization of hydraulic presses costs a lot of money, no matter how short pipe-runs may be kept, but it is indeed the best investment in the end.

On page 284 of Naden's paper I was interested to read that cast containers had been tried. It would have been of interest to have heard for which billet diameters and specific pressures these were employed, and in what steels.

During the discussion some apprehension was expressed by several speakers as to the ability of the extrusion press to ever compete with the older, established methods of carbon-steel tube and profile manufacture. No one would deny that with the more orthodox design of presses in operation, the rate of output achievable is insufficient to compete economically with existing methods of production. However, this is in no small measure also due to the methods of handling so far employed, both of billets and of tools, and not least due to the present need, or desire, to finish to close tolerances in the extrusion press.

The company with which I am associated is now developing new presses with which it is intended to radically change production possibilities from steel extrusion presses, provided that the batch quantity, i.e. the size of any particular programme, the material, the tolerances on the extruded product (and this may imply some secondary equipment beyond the extrusion press for certain applications), and the other well known factors allow this. These presses should then, and we hope and believe that it will not be too long, allow carbon steel tubing to be produced competitively with other, older methods.

It is also the intention to use low-frequency induction heating for such new plants. The experience gained during the last twelve months with a 20 tons/h induction heater installation under conditions of sustained production, has confirmed beyond doubt that this method of heating is today a practical reality, for it is economical in space requirements and running costs, and versatile in operation.

Mr **A. W. H. Banyard** (The Loewy Engineering Co. Ltd) wrote: On page 282 of his paper Mr Naden made some comments on induction heating in general, which appear a little pessimistic in the light of much experience gained in most recent times with low-frequency induction heating. The paper by Mr Cox and his colleagues, shows how they are using their low-frequency induction heating plant to suit their purposes, even on the most complex of extrusions.

If it is possible to extrude 8-finned tubes with preselectable and prearrangeable heat patterns for consistent and sustained production conditions, utilizing ordinary mild steels, then the vision of producing normal tubes under less critical conditions, holds no terrors, and is indeed being carried out in numerous plants.

When Mr Naden writes of the danger of overheating bores of hollow billets, it may well be that he has witnessed tests carried out under conditions of insufficient power-density,

resulting in radiation losses offsetting the heating effects and showing the centre of the billet at a higher temperature than the outside. It is important that tests are carried out with equipment correctly set and adjusted. As mentioned before, the experience in numerous plants has allayed any fears and prejudices that might have existed, and sometimes die a little hard.

Concerning the question of the temperature gradient within a billet, it can certainly be said that it is detrimental to have one side of a billet at a different temperature from the other, a situation which can occur with conventional furnaces, where, for example, the side resting on the hearth is at a different temperature from the other. When extruding unsymmetrically heated billets, uneven material flow results between the die and mandrel, tending to produce eccentric tube. The radial temperature distribution in a billet heated by induction is symmetrical, owing to the very principle of this method of heating. It has been shown that within limits a billet, which has a symmetrical temperature gradient is capable of producing a considerably more concentric tube.

It is also stated that electrical alterations are necessary when changing from non-stainless to stainless, or from solid to hollow billets; it may well be that Mr Naden toyed with the idea of medium frequency heating, utilizing billets of perhaps 5 in. and downwards. With medium frequency heating, certain complications and adjustments appear to be unavoidably associated with the motor-generator equipment.

I have recently seen a plant in Japan where six low-frequency induction billet heaters were recently placed into operation together with a 2000-ton steel extrusion plant, laid out essentially for the manufacture of ball bearing tubes. With four of the induction heaters in operation only, a sustained production of 60 billets per hour was achieved.

A question was raised during the discussion on the use of low-frequency heating for square billets. It might be of interest, that we have just completed fully satisfactory development tests, in which steel ingots weighing up to 12½ cwt were heated to 1230°C without any difficulties whatever.

Mr **R. V. Rowles** (Atlas Works, Gloucester) wrote: In contemplating the problems which emerged I have recalled the early days of my experience, which has been continuous since 1916, in the manufacture of extrusion equipment. When planning for the future it is well at times to review the past.

The papers represent an admirable explanation of the present state of the art, and most valuable data have been made available, by which the respective firms represented have rendered signal service for the benefit of those who may contemplate embarking upon the further exploitation of this process, and which undoubtedly will offer very much greater potentialities as the state of the art progresses. It is evident that the crucial problems to be overcome are metallurgical and chemical.

To take full advantage of the improved mechanical equipment now available, therefore, the aim would appear to be to develop tools that will withstand the thermal, pressure, and scouring effects of the extruded medium, combined with a lubricant which is relatively cheap in current and licensing costs.

The undue and costly repair and replacement of tools today arise from the fact that material is too close in physical and other characteristics to the extruded medium. In my early days in the field of non-ferrous extrusion, the metal extruded was usually 60–40 or 70–30 brass. The press containers were of cast carbon steel, the liners and dies, etc., being of greatly inferior quality to those used today. Even these steels were so greatly dissimilar to the relatively softer and lower-temperature brasses as to enable the extrusion process to make increasingly great inroads on casting and rolling. A quick review of materials used for tools today reveals the metallurgical advances that have been made in the field of non-ferrous extrusion. While I am aware of recent advances in the state of the art of steel extrusion, some of which are not yet generally available, it is greatly to be hoped that metallurgists will accept the challenge and present industry with the opportunity to exploit to the full this truly fascinating process.

As an indication that the mechanical resources are available, reference may be made to the existence in this country of a press which has extruded in another metal tubes 4 in. (outer dia.) × $\frac{1}{16}$ in. thick × over 40 ft long, at the rate of three per min, i.e. 180 per hour; the complete sequence of billet loading, extrusion, severance and disposal of discard, removal of tube, etc. being entirely automatic with push-button control. Can the tooling requirements, therefore, be advanced to match up with the advanced press technique?

Mr **R. J. Courtney** (Henry Wiggin and Co. Ltd) wrote: Low-frequency heating has been discussed in three of the four papers on hot extrusion of steels presented, and the encouraging results reported prompt me to comment on the use of this method for the heating of nickel-base alloys.

Mains frequency induction heating can be used to advantage with nickel–copper and nickel–iron alloys where scaling of the billet would produce disastrous effects not only on the die and liner but also on the product itself. Considerable reduction in oxide penetration has been observed in these products from lf heated ingots compared with those from conventional gas-heated ingots. A protective atmosphere is normally used with these alloys.

Nickel–chromium alloys, however, will not usually oxidize progressively as many steels will, and in consequence the advantage afforded by low-frequency heating in controlling oxidation does not really apply. In fact the product from induction heated nickel–chromium ingots has shown no improvement in surface condition or metallurgical cleanliness over gas heated ingots. Also a rapid heat input, an advantage in steel heating, has been found detrimental to high-strength nickel–chromium alloys; their low thermal diffusivity causes steep thermal gradients which can, and often do, result in rupture of the ingot.

Preheating of the more sensitive alloys to about 250°C will obviously help to reduce initial thermal shock, but heating rates above this temperature must still be kept low, and heating times as high as 60 min have been necessary, when induction heating 9-in. dia. ingots of Nimonic 100.

These comments relate to work conducted on cast ingots and I wonder whether cast ingots of 5%Cr–Mo or 18%W high-speed steel would react to low-frequency heating in a similar way to the nickel–chromium alloys.

While on the subject of cast ingots it would seem that very little has so far been done in this respect with regard to the extrusion of steel. I agree with Mr Cox and his associates that this requires greater consideration. There will, of course, be problems, and not the least of these will probably be in the production of the ingot itself. Since there can be no intermediate overhauling in extrusion the ingot must initially be as near perfect as possible, both structurally and surfacewise.

Manufacture of small ingots by conventional means is tedious and in this respect continuous or semi-continuous casting will probably be the answer. For larger ingots of, for example, 9 in. dia. and greater, uphill casting or Durville casting could be used. Both methods have given, and are still giving, satisfactory results in the extrusion of nickel–chromium alloys. Durville casting of 12 in. dia. can be produced with good internal structure because lower casting temperature can be used, and even at low casting temperature an excellent surface finish which does not require machining is obtained.

The extrusion of cast ingots does itself present problems. In the extrusion of nickel–chromium alloys it has been found that there is a specific efflux velocity at the die which is a constant for a particular alloy irrespective of ratio, but this speed is lower when extruding from cast ingots than when extruding from wrought stock. It is possible that this pattern will also be followed with steel.

A slow extrusion speed, as Mr Cox very rightly points out, will cause dimensional variation from the leading end to the discard end of the product, and it is in this connexion that greater emphasis is needed on improvement in lubrication. It

may be necessary to use composite pads of glass so that the viscosity will vary as the extrusion proceeds. Reference to the paper by Séjournet where he discusses the action of the glass during extrusion will show the problems involved here, since only a very thin layer of glass is used during the complete extrusion.

On simple shapes twin-hole extrusion will enable a longer cast ingot to be used since the effect will be that of extruding a lower ratio and the resulting product will be shorter in length. As suggested by Sukolski and Hoyle a further advantage with multi-holed extrusion may be the elimination of central segregation from the extruded product.

Finally, extrusion from cast ingots requires higher specific pressures, and ratios at present considered suitable when using wrought stock will give difficulty when cast ingots are used. The natural tendency, in these circumstances, is to raise the ingot temperature to increase the range of the press. This has been found impracticable when extruding cast ingots of high-strength nickel–chromium alloys.

Authors' reply

Messrs **Cox, McHugh,** and **Kirk** wrote: We were very interested in Mr Courtney's remarks about the lf induction heating of cast billets. In our experience we have had no particular difficulty in heating 4-in. and 5-in. cast billets in high-strength Ni–Cr alloys using the technique which we have developed for tool steels. Cast billets of 18–8 high-speed steels have also been satisfactorily heated using a short preheating cycle at 800–900°C and thereafter raising as rapidly as possibly to extrusion temperature. The total time of heating for a 5-in. billet being 10 min.

STAL *in English*

Nos.1–3 of the 1960 series of *Stal in English* have been published and subsequent issues will appear at about three-weekly intervals. Principal contents of nos.3 and 4 are given below. Full details of subscriptions to *Stal in English* are available from the Secretary of The Iron and Steel Institute.

No. 3

IRONMAKING

Producing high-basicity sinter from finely ground concentrates

Desulphurization of iron in the blast-furnace

STEELMAKING

Investigation of crust formation in ingots by means of radioactive tracers

Formation of internal flaws in billets during continuous casting

Powder injection into a bottom-blown basic Bessemer converter

Absorption of metal by the OH-furnace hearth

Steelmaking arc furnaces in foreign countries

Use of hot metal in steelmaking arc furnaces

ROLLING AND TUBE PRODUCTION

Two-line rolling of shaped reinforcing bar

Production of large-diameter tubes in the Federal German Republic and France

METAL SCIENCE AND HEAT TREATMENT

Prevention of surface flaws when annealing steel sheet

Cooling billets of high-silicon steel

No. 4

IRONMAKING

Tests on a fluidized-bed furnace for magnetic roasting of iron ores

STEELMAKING

Secondary steel oxidation

Conversion of phosphorus pig iron using solid finishing slag in the charge

ELECTROMETALLURGY

Production of ball-bearing steel

ROLLING AND TUBE PRODUCTION

Calculating roll-pass designs for angle iron

Despatch of rolled products by theoretical weight

Roller entry guides for rolling rounds

Sheet-mill metal consumption

METAL WORKING AND HEAT TREATMENT

New drop-forging steels for hot deformation

The nature of the formation of 'bright spots' in axle steel

Heating and cooling of covered furnace coils

ECONOMICS AND ORGANIZATION

Hidden production losses in sheet-mill shops

HEAT TECHNOLOGY

Conveyor furnace for annealing centrifugally cast pipe

FOUNDRY PRACTICE

Increasing ingot-mould life

Letter to the Editor

Power input control in electric arc furnaces

THE BISRA AUTOMATIC POWER INPUT CONTROLLER (APIC) which adjusts the electrical power input to an arc furnace to any desired programme has been previously described in the *Journal* (May 1959, **192,** 34–39). Operating experience with this equipment on the BISRA 10-cwt experimental arc furnace showed that the timing arrangement was not adequate for every requirement, e.g. for the control of the melting period on a time only basis, and so a new timing circuit has been designed to cater for any size of furnace and different charge weights. The improved timing arrangement consists, essentially, of a synchronous cam-type process timer, a stepping relay, and a single-pole selector switch, connected as shown in Fig.1.

The process timer consists of a synchronous clock motor fitted with a solenoid-actuated clutch. When the solenoid is energized the clutch is engaged and couples the clock to a spindle carrying three cams, each of which is set to close a microswitch, and can be positioned on the spindle to operate their contacts at any time during a six-minute time cycle. By using one, two, or three cams the contacts of the microswitches can be arranged to close every six, three, or two minutes, respectively. De-energizing the solenoid disengages the clutch and resets the timer.

The stepping relay is a solenoid-actuated, solenoid-resetting, single-pole selector switch, with 23 ways. Using all three microswitches the stepping relay will move on to step 2 after one minute, and then on to the remaining 21 contacts at intervals of two minutes, giving a total time generated of $1+(21\times 2)=43$ min. This has been found to be more than adequate for operation of the BISRA furnace. When two microswitches are used the total time generated becomes 65 min, and when only one switch is used the total time is 131 min.

To cater for different charge weights an 11-way single-pole switch is wired to step 4 of bank Z4 of the uniselector (the step corresponding to the highest voltage tap) and the 11 ways on the switch can be connected to any 11 contacts on the stepping relay so as to give a selection of times on the top voltage tap.

The operation of the APIC is essentially as described in the appendix to the paper referred to above, and the improved timing arrangement is fully described in BISRA paper SM/AC/187/59.

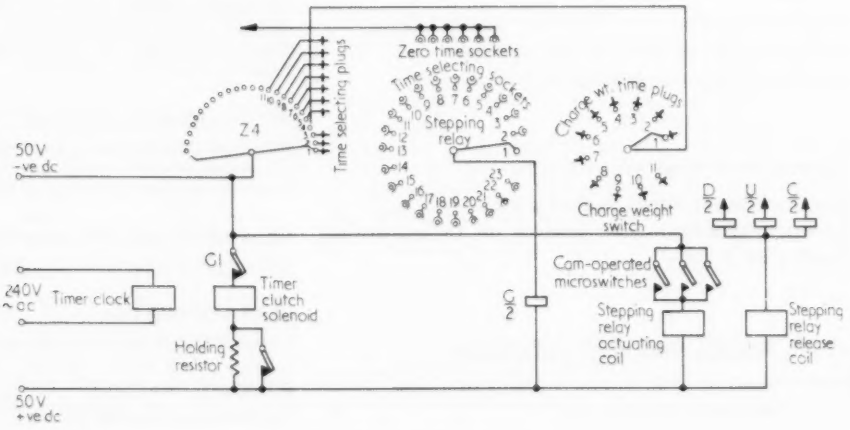
Experience on the BISRA experimental furnace has shown that when melting a charge of 10 cwt of light tube scrap, after five minutes on tap 5 at the start of the melt it is desirable to increase the voltage in one step to the highest (no.8) voltage tap. In this case steps 2 and 3 of the uniselector, corresponding to voltage taps 6 and 7, are connected to the zero time sockets.

At this stage control of power input is governed by time, roof temperature, and rate of temperature rise, and step 4 of the uniselector is connected *via* the charge weight switch to step 9 on the stepping relay, to give a minimum time of 15 min on the top voltage tap. Similarly steps 5, 6, and 7 are connected to zero time, and the minimum times on steps 8, 9, and 10, corresponding to voltage taps 4, 3, and 2, are arranged to be 15, 5, and 5 min, respectively.

The APIC fitted with the improved timing arrangement has been proved on the BISRA furnace using time, roof temperature, and rate of roof temperature rise as the control parameters; it has also been tried successfully on a 5-ton production furnace for power input control during melting, with time as the only control criterion. In the case of the 5-ton furnace, the use of the APIC over a three-week period resulted in an 8% increase in melting rate and a 2% saving in electricity consumption, the charge weight range being 4–8 tons.

J. RAVENSCROFT — *Steel, Peech and Tozer, The Ickles, Rotherham, Yorks.*

L. McGEE — *BISRA, Hoyle Street, Sheffield 3*



1 *Simplified circuit showing improved timing arrangements of BISRA automatic power input controller*

NEWS | *Announcements and News of Science and Industry*

THE IRON AND STEEL INSTITUTE

AUTUMN GENERAL MEETING 1960

The Autumn General Meeting of the Institute will be held at Church House, Great Smith Street, London SW1, on Tuesday and Wednesday, **29 and 30 November 1960,** The programme will consist of two parallel meetings, on fluid flow in furnaces and converters and on martensite, respectively. Preliminary details of the programme of papers are as follows:

Meeting on fluid flow in furnaces and converters

29 November, 9.30–1.00

'Flow patterns in three-dimensional shapes' by N. P. Bacon, J. H. Chesters, and I. M. D. Halliday (United Steel Companies Ltd)

'Aerodynamics in open-hearth furnaces as a means of controlling combustion and heat-transfer processes' by M. A. Glinkov (Moscow Steel Institute)

'Protection of OH furnaces by an auxiliary jet' by J. V. Edwards (Steel Company of Wales Ltd.)

'Aerodynamic and thermodynamic tests on the operation of large soaking pits' by H. Boenecke (OFU–Ofenbau-Union G.m.b.H.)

'Application of aerodynamic design to the U-fired soaking pit' by J. H. Richards (United States Steel Corporation).

29 November, 2.45–4.45

'Aerodynamics of regenerators' by C. Hulse (Sheffield University)

'The effect of flow distribution on air preheat in the open-hearth furnace' by J. Chapman and W. Montgomery (Steel, Peech and Tozer).

30 November, 9.30–12.30

'Mechanics of top blowing' by T. Kootz (August-Thyssen-Hütte AG)

'Hydrodynamics of oxygen lancing processes for steelmaking' by B. S. Holmes and M. W. Thring (Sheffield University)

'The physics of oxygen blowing' by C. Holden and A. Hogg (United Steel Companies Ltd).

In addition to the papers mentioned, there will also be contributions from IRSID (France) and Royal Netherlands Blast Furnaces and Steelworks Ltd, IJmuiden.

It is hoped that these discussions will be of interest to the practical user of furnaces and converters as well as the research scientist; the papers have been chosen to represent work carried out on operational furnaces as well as that being done in the laboratory.

Meeting on martensite

29 November, 9.30–11.30

'Crystallographic features of martensitic transformations' by J. W. Christian (Oxford University) and B. A. Bilby (Sheffield University)

'The morphology of martensite' by P. M. Kelly and J. Nutting (Cambridge University).

29 November, 11.30–1.00

'The kinetics of martensitic transformations' by W. S. Owen (Sheffield University).

29 November, 2.45–4.45

'The effect of carbon and alloy additions on the structure and properties of martensite' by K. J. Irvine and F. B. Pickering (United Steel Companies Ltd)

'The mechanical properties of some tempered alloy martensites' by G. L. J. Bailey and G. Mayer (The Mond Nickel Co. Ltd)

'The hardness of martensite' by D. Hardwick (Brown–Firth Research Laboratories).

The above are the papers forming the nucleus of the discussions. It is likely that several other papers will be included for discussion in the final programme.

The papers for the two meetings will all be published in the *Journal* in the next 6–9 months; papers not published before the meeting will be available in preprint form to those attending.

The final programme of the meeting will be announced in the *Journal* in due course.

SYMPOSIUM ON STEELS FOR NUCLEAR PRESSURE CIRCUITS

A symposium under this title organized by The Iron and Steel Institute will be held at the Hoare Memorial Hall, Church House, Great Smith Street, London SW1, on Wednesday **30 November** and Thursday **1 December 1960.** I will be included in the activities of the British Nuclear Energy Conference of which the Institute is a member.

The symposium will be divided into the following sessions: Factors governing selection of steels, fabrication aspects, irradiation effects, high-temperature properties, corrosion, and steels for future reactors.

Further details will be given in a later issue of the *Journal*.

NEWS OF MEMBERS

Birthday Honours List

O.B.E.

Mr **H. R. Rowbotham,** chairman and managing director of Joshua Bigwood and Son Ltd.

Mr **F. H. Saniter** (*Vice-President*) Director of the Research and Development Department of The United Steel Companies Ltd.

Dr **H. T. Angus** has been awarded the E. J. Fox Medal of the Institute of British Foundrymen for 1960.

Mr **W. E. Bardgett** has been elected President of The Institution of Metallurgists.

Mr **F. C. Bird** has joined the John Folkes Group as consulting metallurgist.

Mr **H. R. Brunyee,** works manager (services) at Steel, Peech and Tozer, retires at the end of this month.

Mr **G. A. Clouston** has joined the Rhodesian Iron and Steel Co. Ltd, Redcliff, Southern Rhodesia.

Mr **F. Coulton** has been appointed a director of Alloy Fabrication Ltd.

Mr **H. M. Crowe** is now with The International Construction Co. Ltd, Ranchi, Bihar, India.

Mr **T. J. Hirst** has joined John Lysaght's Scunthorpe Works as assistant works manager.

Mr **D. E. R. Hughes** has been appointed technical manager of the experimental nuclear department of Rolls-Royce Ltd.

Mr **P. A. Molland** is now general sales manager of Round Oak Steel Works Ltd.

Mr **A. J. Peech** has been appointed a part-time member of the Iron and Steel Board.

Mr **F. G. Phipps** has retired as director in charge of production at Davy–United Engineering Co. Ltd.

Professor **F. D. Richardson** is to deliver the Fourth Robert Horne Memorial Lecture to the Society of Chemical Industry on 29 September.

Mr **T. H. Stayman** has been appointed managing director of Head Wrightson Iron and Steel Works Engineering Ltd.

Mr **G. R. Webster** has been nominated junior vice-president of the Institute of British Foundrymen for 1960–61.

AFFILIATED LOCAL SOCIETIES

North Wales Metallurgical Society

At the Annual General Meeting held on 28 April 1960 the following elections were made:

Chairman: S. McLintock
Vice-Chairman: H. H. Johnson
Treasurer: S. Andrew
Auditor: L. S. Taylor
Hon. Secretary: S. Weir
Asst. Secretary: E. D. Harry
Press secretary: H. M. Newbery
Committee members: H. B. Freeman, M. A. Hall, R. Mayorcas, and E. J. Williams were elected for two years. G. Millington, R. Rippon, I. O. V. Thomas, and R. L. Willott were elected for two years in 1959.

POWDER METALLURGY JOINT GROUP

Winter Meeting 1960

The next meeting of the Powder Metallurgy Joint Group of The Iron and Steel Institute and The Institute of Metals will be held at Church House, Great Smith Street, London SW1, on Thursday and Friday, **15 and 16 December 1960.** One day will be devoted to a symposium on 'The practical aspects of pressing metal powders', while the other will be reserved for the discussion of papers which have been published in *Powder Metallurgy* but which have not been part of special symposia.

The Group is interested to receive papers on all aspects of powder metallurgy with a view to their publication in the journal and subsequent discussion. Manuscripts should be sent to the Secretary, Powder Metallurgy Joint Group, 17 Belgrave Square, London SW1.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Pedigree irons and steels for research

To help research workers in obtaining suitable qualities of iron and steel and associated alloys, the Metallurgy Division of BISRA is to set up a service to provide the necessary materials and give expert advice. A catalogue of the available materials has been published which gives analyses of each material and, where possible, its mechanical properties.

Technical summary 154 gives further details of the scheme and is obtainable from the Metallurgy (General) Division, Hoyle Street, Sheffield 3, to whom all enquiries should be addressed.

THE INSTITUTION OF METALLURGISTS

At the sixteenth Annual General Meeting held on Thursday, 19 May 1960, at the Park Lane Hotel, London, Mr W. E. Bardgett, B.SC., A.M.I.MECH.E., F.I.M., research manager, The United Steel Companies Ltd, was elected President of the Institution in succession to Professor A. J. Murphy, M.SC., F.I.M., F.R.AE.S. After his investiture Mr Bardgett delivered his presidential address entitled 'The effectiveness of the metallurgist in industry'.

The following elections were also made:

President-Elect: Dr N. P. Allen, M.MET., D.SC., F.I.M., F.R.S. (National Physical Laboratory), in succession to Mr Bardgett.

Vice-Presidents: E. A. Bolton, M.SC., F.I.M. (ICI Metals Division); E. G. West, B.SC., PH.D., F.I.M. (Aluminium Development Association).

Hon. Treasurer: L. W. Derry, B.SC., M.SC. (TECH.), F.I.M., M.I.M.M., A.F.R.AE.S. (Battersea College of Technology), in succession to Dr West.

Ordinary members of council elected by Fellows: I. Jenkins, D.SC., F.I.M.; A. H. Sully, M.SC., PH.D., F.INST.P., F.I.M.; Professor C. R. Tottle, M.MET., F.INST.P., F.I.M.

Ordinary member of council elected by Associates: E. Mitchell, A.C.T.(BIRM.), F.I.M.

BRITISH NUCLEAR ENERGY CONFERENCE

1960 Meetings

8 September The Autumn Meeting of The Institute of Metals will be held at the Pump Room, Bath, Somerset, from Monday, 5 September, to Friday, 9 September, and the following discussion, which will take place at 10.00 am on Thursday, 8 September, may be of interest to members of BNEC.

Under the heading 'Magnesium alloys for fuel element components' two papers will be discussed:

'The creep of high-temperature fatigue properties of the magnesium-based canning alloy, Magnox A12' by P. E. Brookes, N. Kirby, and W. T. Burke

'Creep-resistant magnesium alloys for nuclear fuel elements' by G. C. E. Olds and G. M. Michie.

Further details of the meeting may be obtained from The Secretary, The Institute of Metals, 17 Belgrave Square, London SW1.

8 November (5.30 pm) At 1–7 Great George Street, London SW1, at 5.30 pm a meeting sponsored by The Institution of Civil Engineers will discuss the paper:

'Some contributions from nuclear power to engineering', by I. Davidson.

9–10 November A symposium on 'The use of secondary surfaces for heat transfer with clean gases', will be held on Wednesday, 9 and Thursday, 10 November, at The Institution of Mechanical Engineers, 1 Birdcage Walk, London SW1. Information on the papers to be presented will be published in the October issue of the *BNEC Journal*.

Further details of the symposium may be obtained from the Secretary of the Institution.

30 November–1 December The Iron and Steel Institute will be holding a two-day symposium on 'Steels in reactor pressure circuits',

CONTRIBUTORS TO THE JOURNAL

Prof. Dr **M. Signora**—Works general manager, Terni S.p.A., Genoa, Italy.

Mario Signora was born in Budoia di Udine in 1909. He graduated from Padua University in 1932 as doctor of industrial chemistry, and in the following year as doctor of pharmaceutical chemistry. In 1936 he was appointed metallurgist at the Central Institute of Aeronautical Research at Guidonia, and in 1937 he joined the alloy steel division of the Acciaierie di Bolzano as head of the metallurgical laboratories. From 1944 until 1946 he was technical advisor to the Allied Commission for Italian Industrial Recovery, when he joined Acciaierie Lombarde Falck as director of research. From 1955 to 1959 he was works director at Breda Siderurgica. He took up his present post in 1959.

Professor Signora is a lecturer in metallurgy at Rome University and vice-president of the technical committee of the Italian Standards Institute (UNSIDER). He is a member of The Iron and Steel Institute, the AIME, and the VDE.

Dr **R. Cardano**, A.I.M.—Melting shop manager, Terni S.p.A.

Renato Cardano was born in Naples in 1918 and graduated from Naples University in 1939 as doctor of chemistry. He entered the laboratories of the Alfa Romeo aircraft factory, then in 1946 he joined Terni. He became works metallurgist in 1958 and in the same year he

Prof. Dr M. Signora

Dr R. Cardano

was appointed to his present position. He is a member of The Iron and Steel Institute and the VDE.

Prof. **A. Scortecci**—Head of research, FINSIDER, Italy.

Antonio Scortecci graduated from the University of Florence as a chemist in 1919, then spent ten years as head of the physics and

Prof. A. Scortecci

Prof. Dr A. Palazzi

chemistry departments of the Breda Technical Institute in Milan. In 1930 he was appointed head of the laboratories of the Ansaldo steelworks where he remained until 1937 when he became manager of a plant of the Illsa Viola Company in Northern Italy. This was followed by five years as production vice-president of the ILVA Steel Company, then in 1949 he became head of the FINSIDER research institute.

Professor Scortecci is also professor of metallurgy and metallography in the University of Genoa, vice-president of the Committee of Cooperation in Research of OEEC in Paris, an honorary member of the French Society of Metallurgy, and a member of the Research Committee of the ECSC. In 1958 he was awarded the Le Chatelier Medal of the French Society of Metallurgy.

Prof. Dr **A. Palazzi**—Head of Metallurgical and Process Chemistry Department, FINSIDER, Genoa.

Aurelio Palazzi is a chemist and professor of metallurgy. His department is concerned with problems of industrial research and control of blast-furnaces, coke ovens, and steelmaking. He has been responsible for extending the scope of experimental work and statistical quality control and other statistical methods throughout the industry and research institutes in Italy.

Professor Palazzi is a former vice-president of the Italian Association for Quality Control (AICQ) and is author of numerous technical publications on statistical methods and metallurgy.

R. J. Brown

R. Brook

E. F. Ibrahim

Dr N. P. Bacon

R. J. Brown, F.I.M., A.M.I.MECH.E.—Chief materials engineer, British Motor Corporation.

Robert James Brown was born in 1910 at Teignmouth and educated at Coventry Junior Technical School and Birmingham Technical College. In 1929 he joined Morris Motors Ltd as foundry chemist and was appointed chief metallurgist in 1935. When the Nuffield Central Research Laboratories were established in 1946 Mr Brown was made responsible for them, and in 1955 he was appointed to his present post in control of the work of all BMC laboratories.

Mr Brown is a member or fellow of a number of technical institutions, and a member of council of the BNFMRA and the Institute of Metal Finishing. He is also a member of several committees of the British Standards Institution.

R. Brook, M.MET.—Research student, Sheffield University.

Mr Brook was born in 1932 at Grenoside, near Sheffield and was educated at Ecclesfield Grammar School before joining the metallurgical and research department of the English Steel Corporation in 1948. He obtained the HNC in metallurgy at the Rotherham College of Technology before entering the RAF in 1954 to complete his National Service. In 1956 he was awarded an ESC scholarship to Sheffield University, where he gained his A.Met. and M.Met. degrees. He returned to the research laboratories of the English Steel Corporation in 1958, and at present, under an ESC bursary, he is working at Sheffield University for his Ph.D. degree in metallurgy.

E. F. Ibrahim, M.MET.—Research and development laboratories, UKAEA, Windscale.

Edward F. Ibrahim was born in 1936 and in 1953 joined the research laboratory of Darwins Ltd, at the same time studying for the HNC in metallurgy at Sheffield College of Technology. He then studied at Sheffield University to obtain his degrees of A.Met. and M.Met., and in 1958 he joined the UKAEA at Windscale.

N. P. Bacon, PH.D., B.ENG.—Research engineer, Guest Keen Iron and Steel Company, Ltd.

Norwood Peter Bacon was educated at Dronfield Grammar School before beginning his initial technical training at Steel, Peech and Tozer. For three years he was engaged on flying duties with the RAFVR, then in 1947 he entered Sheffield University where he gained the degree of B.Eng.(Fuel) in 1950. In 1955 he was awarded his doctorate for research on an experimental reheating furnace under the supervision of Professor R. J. Sarjant.

Dr Bacon then worked in the furnace and fuel section of The United Steel Companies Research and Development Department on model studies and pilot-scale experimental furnaces. He took up his present appointment in 1957.

INSTITUTE OF WELDING

Autumn Meeting 1960

The 1960 Autumn Meeting will be held from 1 to 3 November in London, and will be devoted to the metallurgy of welding and brazing. The Annual Dinner of the Institute will be held on the evening of Thursday, 3 November.

School of Welding Technology, autumn courses
Course D.1/3. Welded pressure vessels, 26–30 September
Course D.13/2. Residual stresses and stress relief, 10–11 October
Course D.18/1. Metal spraying, 24–27 October. Further details of these courses are obtainable from the Secretary, The Institute of Welding, 54 Princes Gate, Exhibition Road, London SW7.

INSTITUTE OF PHYSICS AND THE PHYSICAL SOCIETY

Amalgamation

The incorporation of a new body on 17 May, under the name of 'The Institute of Physics and The Physical Society' marks the implementation of a scheme for amalgamation prepared by a Joint Committee of the two bodies and approved by an overwhelming majority of members. The originating bodies will shortly be formally wound up and their assets handed over to the new one.

The first President of the amalgamated body is Sir John Cockcroft and the four Vice-Presidents are Dr J. Topping, Dr W. H. Taylor, Professor R. W. Ditchburn, and Mr A. J. Philpot, each responsible to the Council for a defined area of the many activities to be taken over by the new organization from its predecessors. The Presidents of the predecessors (Sir George Thomson and Mr J. A. Ratcliffe) are also members of the new Council. The other officers are Dr J. Taylor (Honorary Treasurer) and Dr C. G. Wynne (Honorary Secretary).

The qualification for the award of Fellow of The Institute of Physics, Associate of The Institute of Physics, and Graduate of The Institute of Physics will remain unchanged and members of the new body holding these diplomas will also be Fellows of The Physical Society. Besides the three Institute of Physics grades of membership of the new body there will also be the grade to be known as 'Fellow of The Physical Society'. All the Fellows of the old Society will be automatically transferred to this new grade, but new candidates for election to the grade will be required to possess a degree or diploma in physics recognized by the Council, or satisfy the Council that they have a sufficient knowledge of physics.

The executive officers of the new body are:
Secretary: Dr H. R. Lang
Editor and Deputy Secretary: Dr A. C. Strickland
Deputy Secretary: Mr N. Clarke.

The registered offices and headquarters are at 47 Belgrave Square, London SW1, and for the present, offices will also be retained at 1 Lowther Gardens, London SW7.

EDUCATION

Computer courses

Computer Consultants Ltd in collaboration with computer and associated equipment manufacturers announce two further courses on the business application of electronic computers, to be held in London on 12 September and 7 November. Further details are obtainable from Computer Consultants Ltd, Cecil Court, London Road, Enfield, Middlesex (ENF 7185).

Work study

The School of Work Study is holding a series of full-time courses at its headquarters, 11 Old Burlington Street, London W1. Courses of six-weeks duration begin on 8 August, 19 September, and 7 November, and are designed to train work-study officers to a level at which they will be able to act as assistants, observers, and administrators in works and offices where work study is being applied. There is a strong emphasis on rating techniques and two weeks are spent under supervision in factories or offices.

One-week appreciation courses intended for supervisors, planning engineers, and those associated with the application of bonus incentive schemes will be held on 8 August and 7 November.

FORTHCOMING CONFERENCES AND EXHIBITIONS

Brno Trade Fair 1960

Preparation for this year's Brno Trade Fair are well under way, according to the latest bulletin issued by the organizers. The fair will be held from 11 to 25 September, and nearly 600 exhibitors from countries outside Czechoslovakia are participating. From 13 to 23 September it is planned to hold 'specialist days of new technology' including discussions on data processing machines, machine tools and modernization, large rotary machines, surface finishing, electronic control in automation, and material handling.

Ultrasonic inspection

A conference on the 'Theory and practice of ultrasonic inspection' is to be held at the Queens Hotel, Cheltenham, during 22–24 September 1960. The arrangements are being made jointly by The Institute of Physics and The Physical Society Non-Destructive Testing Group, The Society of Non-Destructive Examination, and The Non-Destructive Testing Society of Great Britain. Further details may be obtained from the Conference Secretary, Mr I. M. Barnes, Materials Laboratory, de Havilland Propellers Ltd, Hatfield, Herts.

Ergonomics

Ergonomics, the study of man in relation to his working environment, is the subject of a three-day conference being organized by the Department of Scientific and Industrial Research at the Connaught Rooms, Great Queen Street, London WC2, from 27 to 29 September. The object of this conference is to bring recent ergonomic research and industrial application to the notice of senior people in industry and to show where ergonomics fits in with the interests of production engineering, equipment design, work study training, and industrial health.

Further details of the conference (probable fee, inclusive of coffee, lunch, and tea, 15 *gns*) can be obtained from Miss H. M. Clay, DSIR, 14–18 Cornwall Terrace, London NW1. As accommodation is limited, early application is recommended.

NEWS OF SCIENCE AND INDUSTRY

International Congress on metallic corrosion

The Executive Committee of the Congress which is to be held in London on 10–15 April 1961, have appointed the following plenary lecturers: Professor Y. M. Kolotyrkin (USSR), Professor P. Lacombe (France), and Professor H. H. Uhlig (USA). It is hoped that Dr U. R. Evans (UK) will be the fourth lecturer.

The response to invitations to submit papers to the congress has been excellent, and so far papers have been accepted from 17 countries.

BISF Annual Report

The British Iron and Steel Federation recently issue its report for 1959. Part of the speech by Mr Richard Summers, delivered at the Annual General Meeting of the Federation on 15 March 1960, is reproduced as a foreword to the Report. (Mr Summers succeeded Mr L. Chapman, C.B.E. as president of the Federation at the beginning of 1960.) The report contains sections on organization, steel production and supplies, transport and market development, raw materials, finance costs and prices, development and research, manpower, information and publicity, and international affairs. Appendices include a brief but interesting 'world steel picture', and a useful list of publications on iron and steel.

Printed in black and red the report is well illustrated with tables and graphs, and copies are obtainable from the Information Office, Steel House, Tothill Street, London SW1.

Memorial Lectures

The Society of Chemical Industry has announced that the Fourth Robert Horne Memorial Lecture will be delivered by Professor F. D. Richardson, D.SC., PH.D., M.I.M.M. (professor of extraction metallurgy at the Imperial College of Science and Technology), on 29 September in Bristol. The title of the lecture is 'The extraction of metals and the chemistry of melts'.

Dr W. J. Kroll of Corvallis, Oregon, has been appointed the sixth Castner Memorial Lecturer and will deliver his lecture entitled 'The fusion electrolysis of titanium' in Glasgow on Friday, 7 October 1960.

Further details of both these lectures will be announced later, and anyone interested is invited to attend.

Formation of ore investment company

A new company, British Ore Investment Corporation Ltd (BOIC) has been formed by nine of the principal UK steelmaking firms using imported ore and by British Steel Corporation Ltd, an investment-holding company associated with the British Iron and Steel Federation. The main object of BOIC is to hold investments in overseas ore-mining companies, a function formerly undertaken for the UK steel industry by British Steel Corporation alone.

The new company has taken over British Steel Corporation's 20% interest in Société des Mines de Fer de Mauritanie (MIFERMA), a £60 m. project in French West Africa. The ultimate intention of MIFERMA is to produce 6 m. tons of iron ore a year. The ore will be transported on a railway, to be specially constructed, over a distance of about 400 miles to a port to be built near Port Etienne in Mauritania.

Foundry record

A record output of 2704 tons of ingot moulds, bottom plates, slag ladles, and general engineering castings was produced in the iron foundry of Distington Engineering Company Ltd, during the week ending 7 May.

This follows an earlier British and European record for an ingot mould foundry which was set up by Distington in February of this year when over 2500 tons of finished castings were produced in one week. These continual high outputs are enabling the company to keep pace with the increasing demand from its customers in the steel industry.

Italian subsidiary

As the first step in a policy of expansion in the export field, Ether Langham Thompson Ltd announced the recent formation of a new subsidiary, Ether Langham Thompson (Italiana) Ltd, with offices and factory located at Via Bisleri 19, Milano, Italy.

This new company will market and manufacture products of the subsidiary companies of Ether Langham Thompson Ltd, namely Ether Ltd, J. Langham Thompson Ltd, Electro Methods Ltd, Datum Metal Products Ltd, and Automation Systems and Controls Ltd. In addition, agency agreements have been completed between the Italian company and a number of other well known UK and international companies engaged in the field of instrumentation.

Contract news

The *General Electric Co. Ltd*, in association with *Vacuum Industrial Applications Ltd*, has received an order from The British Steel Castings Research Association for a vacuum melting and casting furnace for use in the Association's Experimental Foundry at East Bank Road, Sheffield. With a chamber mounted horizontally and 36 in. dia. the furnace is to be used for research into the melting and casting of steels under vacuum and is capable of melting 56 lb of steel. The working pressure of the furnace chamber is

1 μ Hg and a working temperature of up to 1 700°C can be achieved.

Also, the above companies in association with the *British Geco Engineering Co.*, have secured an order approaching £100 000 in value from Jessop-Saville Ltd for the supply of an induction melting furnace of 1 ton capacity. This is believed to be the largest furnace of its type being manufactured in the UK and it is scheduled for installation in the company's Brightside works, Sheffield, by the end of the year.

The *Head Wrightson Machine Company Ltd*, a subsidiary of Head Wrightson and Co. Ltd, have received an order from Maschinenfabrik Sack, G.m.b.H., Dusseldorf, for the provision of equipment for a complete billet mill. The value of the contract is about £700 000 and includes the intermediate roller tables, cooling banks, and mill drives. The equipment is to be installed at the Redbourn Works of Richard Thomas and Baldwins Limited from whom Sack have received a contract for the supply of the complete mill.

The manufacture of the plant will be completed at the Middlesbrough and Thornaby works of Head Wrightson.

INDUSTRIAL PUBLICATIONS RECEIVED

Leaflet no.V59(1) from the Incandescent Heat Co. Ltd is entitled *Incandescent Gas Atmospheres Division—What we make* and is first of a series.

The Morgan Crucible Co. Ltd has issued the following literature: AE/11 *In the melting pot*, RD.80/1 *Morgan Refractory News:* and GP.59/60 *Foliac colloidal graphite for drop forge die lubrication*' From Morgan Refractories Ltd comes leaflet RD.84 *Refractories in the iron and steel industries.*

The latest issue of the *Journal of Applied Pneumatics*, published by Martonair Ltd, contains features dealing with the various applications of pneumatic equipment.

A booklet from the National Coal Board puts *The case for coal.*

The 'Craven' Machine Tool Gazette no.105 describes some of the products of Craven Brothers (Manchester) Ltd.

A leaflet from The Tempered Spring Co. Ltd, Sheffield, outlines some of the applications of the Rollpin spring pin fastener.

Stillite Products Ltd have issued a revised technical data sheet on the use of lightweight mineral wool slabs as a backing for refractory linings.

Inco-Mond Magazine no.13 includes articles on maintaining London's buses, stainless steel in architecture, solenoid valves, and parking meters.

Henry Wiggin and Co. Ltd have issued a booklet *An introduction to Wiggin nickel alloys.* Also available is a new edition of their publication no.1808, consisting of engineering data on Nimonic alloys.

A new series of hydraulic accumulators is described in a leaflet from Industrial Hydraulics Ltd.

Metalworking Bulletin for June 1960 from the Union Carbide Company includes an article on stokers for a nuclear furnace.

CHANGES OF ADDRESS AND TITLE

The factory and offices of Royce Electric Furnaces Ltd and Metal Welding and Fabricating Co. Ltd are now at Albert Drive, Sheerwater, Woking, Surrey (telephone Woking 5401–4).

Crofts (Engineers) Ltd have opened a new stock-holding branch in Birmingham at 253–255 Great Lister Street.

Head Wrightson Colliery Engineering Ltd of Sheffield, a subsidiary of Head Wrightson and Co. Ltd, Thornaby-on-Tees, have announced that the Company's name has been changed to Head Wrightson Minerals Engineering Ltd.

Union Carbide International Company are now located at 270 Park Avenue, New York 17, NY.

DIARY

25 June – 8 July INTERNATIONAL MACHINE TOOL EXHIBITION—Olympia, London.

28–30 June INSTITUTE OF MINING ENGINEERS—Conference—Cardiff.

4–7 July ELECTRONIC COMPUTING CONFERENCE—Harrogate.

5–6 July BRITISH IRON AND STEEL RESEARCH ASSOCIATION—Conference on heat-treatment practice—Harrogate.

30 July – 7 Aug. SWEDISH INDUSTRIES FAIR—Malmo, Sweden.

5–14 Aug. INTERNATIONAL TRADE AND EXPORT FAIR—Dornbirn, Austria.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on page 214 of the June 1960 issue of the *Journal*.

Measuring the degree of reduction in temper rolling.
BILLIGMANN, J. *et al.*, *Stahl u. Eisen*, 1959, July 9, pp.977–989. (£8 10*s.* 0*d.*) [**1412**

The effect of pre-treatment of the charge in blast-furnace operation.
KAHLHÖFER, H. *et al.*, *Stahl u. Eisen*, 1959, Oct. 15, pp.1461–1471. (£7) [**1492**

Welding of ferritic to austenitic steels.
CLASS, J., *VGB Mitt.*, 1959, June, pp.181–207. (£9 15*s.* 0*d.*) [**1516**

Research into the formation and elimination of deoxidation products.
PLÖCKINGER, E., and WAHLSTER, M., *Stahl u. Eisen*, 1960, May 12, pp.659–669. (£7) [**1544**

The completion of basic Bessemer conversion.
MAROT, J., and HARVENG, J., *Rev. Mét.*, 1959, Oct., pp.211–220. (£4 15*s.* 0*d.*) [**1546**

Ultrasonic determination of the size of defects.
KRAUTKRAMER, J., *Arch. Eisenhüt.*, 1959, Nov., pp.693–703. (£7 15*s.* 0*d.*) [**1566**

Relationship between the hydrogen contents of slag and metal and the steelmaking process.
BEGLETSOV, I. N., *Stal. Steelmaking Processes Supplement*, 1958, pp.285–313. (£7 15*s.* 0*d.*) [**1572**

Weldability of 13%Cr steels used for castings.
PILOUS, V., and JANDOS, F., *Slevarenstvi*, 1959, May, pp.191–194. (£4 15*s.* 0*d.*) [**1585**

Isolation and determination of oxide inclusions in high chromium steels and experimental isolation of oxides in 18–8 steels.
PIPER E. *et al.*, *Radex Rund.*, 1957, March, pp.776–778. (£3 15*s.* 0*d.*) [**1596**

Report on standardization of methods of testing coke quality.
ERKIN, L. I., *Koks i Khim.*, 1958, (8), pp.58–60. (£3 10*s.* 0*d.*) [**1599**

Isothermal transformation diagrams for four Swedish standardized *spring* steels.
MOLINDER, G., *Jernkont. Tekn. Rad.*, 1958, (248), pp.155–164. (£2 5*s.* 0*d.*) [**1602**

Isothermal transformation diagrams for some Swedish standardized *tempering* steels.
MOLINDER, G., *Jernkont. Tekn. Rad.*, 1959, (255), pp.405–430. (£4 5*s.* 0*d.*) [**1603**

Modern forging manipulators.
PAPULI, G., *La Metallurgia Italiana*, 1959, (3), pp.94–100. (£5) [**1619**

Electronic crane weighing scales for use in iron- and steelworks.
KNÜPPEL, H., and WIETHOFF, G., *Stahl u. Eisen.*, 1960, vol.80, Feb. 18, pp.220–233. (£9 5*s.*) [**1652**

The new 1 400 hp diesel-electric locomotives of the types 040 DG constructed for the French National Railways (SNCF).
CAIRE, D., *Ref. Ass. Française des Amis des Chem. de Fer*, 1959, Nov.–Dec., pp.164–166. (£2 5*s.*) [**1653**

The why's and wherefore's of track maintenance problems.
PORCHER, B., *Rev. Ass. Française des Amis des Chem. de Fer*, 1959, Nov.–Dec., pp.176–186. (£7 10*s.* 0*d.*) [**1654**

Oxidation of heat-resistant steels: Effect of alkaline sulphate deposits in the simultaneous presence of traces of sulphur trioxide in furnace gases.
RAHMEL, A., *Arch. Eisenhüt.*, 1960, Jan., pp.59–65. (£4 5*s.* 0*d.*) [**1659**

Study on the hot-workability of steels. V. Hot working properties of austenitic stainless steels.
MORISHIMA, T., *Tetsu to Hagane*, 1956, Sept., pp.928–930. (£8 5*s.* 0*d.*) [**1665**

Some problems in the manufacture of seamless stainless steel tubing by the Mannesmann plug mill process.
NAKAJIMA, S., *Tetsu to Hagane*, 1957, June, pp.663–668. (£6 5*s.* 0*d.*) [**1666**

The effect of the method of deoxidation on the nature of the non-metallic inclusions and mechanical properties of steel.
MANDL, M. *et al.*, *Hutnické Listy* (Prague), 1960 (2), pp.109–119. (£10) [**1668**

Suitability of blast furnace slag as bituminous aggregate for road building. (With discussion.)
SEND, A. *et al.*, *Stahl u. Eisen*, 1960, March 3, pp.290–296. (£5) [**1679**

Tasks and organization of a quality control department in an iron- and steelworks and its importance to the operation.
FRÖBER, H., *Stahl u. Eisen.*, 1959, Oct. 29, pp.1627–1637. (£7 10*s.* 0*d.*) [**1690**

From cellulose to anthracite. IX. Experimental contribution: thermal hydrolysis of cellulose.
GILLET, A., and COLSON, P., *Brennstoff-Chemie*, 1958, Feb. (special issue), pp.S17–S19. (£1 15*s.* 0*d.*) [**1694**

Generation of gases for the reduction of iron ores.
GRATKOWSKI, H.-W., *Stahl u. Eisen*, 1960, March 31, pp.397–407. (£6 5*s.* 0*d.*) [**1695**

Progress in the application of oxygen in the open-hearth furnace.
FORESI, M., and MASSOBRIO, G., *Met. Ital.*, 1959, July, pp.257–273. (£9 15*s.* 0*d.*) [**1702**

Production, properties, and economic importance of rimming open-hearth steel.
NETTER, P., *Neue Hütte.*, 1960, Feb., pp.63–69. (£5 5*s.* 0*d.*) [**1705**

Potentiostatic isolation of structural components in nickel alloys.
ILSCHNER-GENSCH, C., *Arch. Eisenhüt.*, 1960, Feb., pp.97–102. (£4 5*s.* 0*d.*) [**1706**

Investigations on cement and concrete with exo-electrons after exposure to X-rays.
KRAMER, J., *Zement-Kalk-Gips*, 1960, (3), pp.111–118. (£5 5*s.* 0*d.*) [**1707**

Contribution to the problem of carbide banding in anti-friction bearing steel.
ECKSTEIN, H. J., *Neue Hütte*, 1959, May, pp.304–311. (£4) [**1712**

Heat transfer from the wall to a turbulent flow of air inside a tube with large temperature differences and a method for calculating wall temperature.
DYADYAKIN, D. V., and LEL'CHUK, V. L., *Teploenergetika*, 1958, (9), pp.74–79. (£4 5*s.* 0*d.*) [**1714**

Determination of tin and antimony in steel.
BRHÁČEK, L., *Hutnické Listy* (Prague), 1957, (2), pp.140–141. (£2 15*s.* 0*d.*) [**1715**

Requirements of building industry.
RIESS, H., *Hutnik* (Warsaw), 1951, (6), pp.234–235. (£2 5*s.* 0*d.*) [**1725**

The effect of oxygen on the quality of rimming steels.
PROCHÁZKOVÁ, I., *Hutnik* (Prague), 1958, (2), pp.51–53. (£3 5*s.* 0*d.*) [**1741**

Iron and Steel Translations 1958/59, *the second classified list of BISI translations is now available gratis on request. It contains a subject index for 1958–59, and a cumulative author index which also covers the previous list (1957–58). Copies of the latter are still in print.*

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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* Abstracts, the references to which is marked with an asterisk are, or are to be available as translations.

ABSTRACTS

These abstracts are also available on index cards in advance of publication in the *Journal*, each abstract being classified under the Universal Decimal system (UDC). Details and subscription notes can be obtained from the Secretary, The Iron and Steel Institute.

MINERAL RESOURCES

Iron ore resources of the United States including Alaska and Puerto Rico 1955 M. S. Carr and C. E. Dutton (*US Geol. Survey, Bull.*, 1082–C, 1959, pp.134).

The rhodonite specular iron ore mineralisation at the 'Neue Haardt' mine in Weidenau/Siegerland G. Stadler (*Z. Erz. Met.*, 1959, **12**, Dec., 603–608).

ORES, MINING AND TREATMENT

The development of strip mining in the Northampton sand and Frodingham ironstone fields T. M. Dover (*Mine Quarry Eng.*, 1960, **26**, Jan., 14–20) An account of developments in opencast mining practice with illustrations of machinery at work.

Recovering iron concentrates from the Pea District deposit, Central Missouri D. W. Frommer and M. M. Fine (*US Bur. Mines Rept. Invest.*, 5550, 1960, pp.14) Magnetic separation, flotation, and the two combined were tested

Malaya's iron ore industry expands (*Min. J.*, 1960, **254**, Jan. 15, 62–63) The 1959 production has exceeded 3×10^6 tons.

Iron ore carrier (*Iron Steel*, 1960, **33**, Jan., 19–20) The main features of the Australian 19000-t carrier are described with illustrations.

Orinoco scraper speeds stockpile feed C. H. Hubbell (*Eng. Min. J.*, 1960, **161**, Jan., 85–87) The operation of the 10 cu. yd. cableway drag scraper unit installed by Orinoco Mining Co. at Puerto Ordaz, Venezuela is described. The ore is removed by the scraper, after blending, into two tunnel conveyors to the loading dock.

Giant ore unloaders in the U.S.A. O. Wichern (*Demag News*, 1959, (156), 17–26; from *Fördern und Heben*, 1959, **3**) An illustrated account of the new plant on Chesapeake Bay supplied by a German firm.

Chilean mine continuously ships iron ore during port expansion program P. Soros (*Eng. Min. J.*, 1959, **160**, April, 96–98) The plant at Huasco is illustrated with extended captions.

Recent developments in iron ore concentration G. E. Davies (*Mine Quarry Eng.*, 1960, **26**, April, 158–163) A brief review of sources followed by accounts of gravity, flotation, magnetic, and chemical processes are given.

The beneficiation of Lorraine ores M. Lelong and P. Emery (*Rev. Mét.*, 1960, **57**, Jan., 13–20) By magnetic separation, concentrates with 40–42%Fe can be obtained, by the use of which slag weight can be limited to 700–800 kg/t of Fe. Self-fluxing concentrates with 50%Fe can be obtained, but their use in the blast-furnace has still to be investigated.

Suggested lines of development of modern ore preparation plants H. Bachmann and E. Greulich (*Neue Hütte*, 1960, **5**, Feb., 61–62) The article briefly refers to East German practice.

High-efficiency classifiers help beneficiate iron ore (*Iron Steel Eng.*, 1959, **36**, Sept., 195–196) The high-efficiency classifiers introduced by Buell Engineering Co. of New York have been applied to the beneficiation of iron ore and the preparation of limestone for sintering. Three types are available and are described—the centrifugal, gravitational–inertial, and gravitational classifiers.

Beneficiation of low grade ferromanganese K. M. Pai; R. Mallikarjunan, and A. A. Krishnan (*Trans. Indian Inst. Met.*, 1959, **12**, Sept., 299–303) Low-grade ferromanganese mixture containing 43%Mn and 34%SiO_2 was concentrated by superpanning, tabling, or by heavy media separation in bromoform. Flotation was unsuccessful. The concentrates containing 66%Mn could be briquetted and sintered at 850°C.—A.D.H.

Thermal beneficiation of low grade chrome ores R. N. Misra, M. C. Sen, and P. P. Bhatnagar (*Trans. Indian Inst. Met.*, 1959, **12**, Sept., 221–234) Low grade Indian chromites having Cr:Fe<3 cannot be upgraded by conventional beneficiation methods as the iron is combined as chrome spinel. The preferential reduction of iron oxide by coke-oven gas at 950–1150°C for 1 h followed by leaching of iron with H_2SO_4 yielded a product with Cr:Fe=73 and a Cr recovery of 80%.—A.D.H.

Stanton's new ore preparation plant at Ilkeston (*Gas Times*, 1959, **93**, Oct., 38; *Found. Trade J.*, 1959, **107**, Dec. 10, 586–587) The plant will process 25000–30000 t/week and production from the blast-furnace almost entirely goes for foundry remelting.

Elimination of arsenic from a manganese ore (Djebel Guettara—Sahara) J. Astier and G. Turpin (*Rev. Mét.*, 1960, **57**, Feb., 93–94) An investigation by IRSID into the elimination of As from ores containing an average of 0·4–0·5%As is described. Of the methods examined roasting in the presence of a solid reducing agent, combined with sintering in a rotary furnace, was tried on the semi-industrial scale with satisfactory results, with an average As removal of about 80%.

Agglomeration of finely divided manganese concentrates N. M. Babushkin, V. A. Shamarin, and I. V. Lugovykh (*Stal'*, 1960, (2), 97–104) Sintering and briquetting tests are described. More work is contemplated.

Agglomeration tests made in new pilot plant Allis-Chalmers Co. (*Blast Furn. Steel Plant*, 1959, **47**, Oct., 1071–1072) The programme of work in progress at the new process pilot plant put into operation at Carrollville, Wisconsin, dealing with pelletizing is indicated.

Briquetting: Production of blast furnace briquettes which prevent low temperature carbonisation W. Petersen and S. Wawroschek (*Forsch. Wirts. Nordrhein–Westfalen*, 1958, (625), pp.90) The raw material components are discussed (flue dust, roasted pyrites, red mud, magnetic concentrate, etc). Emphasis is laid on the choice of correct particle sizes, and their distribution for the different materials is tabulated. Equations are given for the thermal efficiency of different brown coal concentrations and mixtures and graphs are presented showing the relationship between kg/cm² and temp. in respect of composition, pressure, and moisture content. The necessary addition of ground limestone, $Ca(OH)_2$ and SiO_2 is also examined in some detail and the effect of the changes from m.p. to solidification temp. and of humidity is also discussed.

Physical properties of Cherepovets Works fluxed sinter N. M. Yakubtsiner, S. K. Trekalo, and A. B. Shur (*Stal'*, 1960, (1), 14–18) The various raw materials going into the sinter and the screening processes and conditions of handling and storage are described.

Experience with self-fluxing sinter at the Steel Company of Canada Limited. Part II J. S. McMahan (*Blast Furn. Steel Plant*, 1959, **47**, Aug., 852–856) Discussion on the above paper (*ibid.*, 1959, **47**, July). Experience of other concerns is reported.

FUEL—PREPARATION, PROPERTIES, AND USES

Chemical structure and properties of coal. XXIV. Sound velocity and fraction of aromatic carbon D. W. Van Krevelen, H. A. G. Chermin, and J. Schuyer (*Fuel*, 1959, **38**, Oct., 483–488).

A note on the relation of specific volume of coals to their hydrogen and oxygen contents S. Ergun, M. Mentser, and H. C. Howard (*Fuel*, 1959, **38**, Oct., 495–499).

Modern coal preparation practice in Britain A. Jowett (*Tidsskr. Kjemi. Bergv. Met.*, 1959, **19**, Aug. 20, 102–110).

General trends in coal dressing and French contributions to techniques in this field M. H. Fournol (*Ann. Mines*, 1960, Feb., 65–76) An illustrated review.

The separability of pyrite particles in some pulverized coals W. Van Hees (*Fuel*, 1959, **38**, Oct., 419–424).

A modification of Mott's method for the determination of pyritic sulphur in coal W. Van Hees and E. Early (*Fuel*, 1959, **38**, Oct., 425–443).

Thermo-gravimetric studies of coal and model substances J. A. Corrales and D. W. Van Krevelen (*J. Inst. Fuel*, 1960, **33**, Jan., 10–16).

Irregularities of swelling curves in euplastic coals K. Gardelka and P. Dvořák (*Fuel*, 1960, **39**, March, 141–145).

Number of free radicals in coal during carbonization at different heating rates J. Smidt

and D. W. Van Krevelen (*Nature*, 1959, **184**, Aug. 29, 719–720) An electron spin resonance study is briefly reported.

The influence of the plasticity of coal on the quality of coke H. C. Wilkinson (*Gas World—Coking*, 1960, **151**, March 5, 39–41, 46).

Influence of aerial oxidation on the binderless briquetting of coals M. S. Iyengar and R. S. Ghosh (*Fuel*, 1960, **39**, March, 113–117).

Research laboratory provides means for full testing of coking coals Eastern Gas and Fuel Associates (*Blast Furn. Steel Plant*, 1959, **47**, Oct., 1061–1062) The facilities available at the new laboratories completed at Everett, Mass. are described.

X-Ray studies of some carbonized coals R. Diamond (*Phil. Trans. Roy. Soc.*, 1960, 252A, Jan. 28, 193–223) Vitrain coals after heating up to 1 000°C were examined.

Prediction of coke quality from the composition of coking coal blends of medium- and low-volatile coals D. W. Van Krevelen, F. J. Huntjens, and A. H. Wilms (*J. Inst. Fuel*, 1960, **33**, Jan., 3–9) Experiments in steel cylinders in a technical oven show the importance of particle size distribution on coke quality.

Port Kembla coking plant (*Coke Gas*, 1960, **22**, Feb., 51–59) An illustrated description with plan.

Calculating coke oven pushing schedules B. S. Gould jun. (*Blast Furn. Steel Plant*, 1959, **47**, Sept., 955–961) Design of coke-oven schedules is considered from the points of view of maintaining uniform oven heating, flue temperatures, and minimum heat losses and ensuring that forces acting on oven walls are minimized. It is also shown how the ideal schedule may be modified to suit particular conditions.

Structural heterogeneity in coke R. Zoja, L. Benussi, and M. Caveri (*Rev. Mét.*, 1960, **57**, Feb., 161–165) A description is given of investigations of the important structural anomalies observed on the macroscopic scale in specimens of coke. Relations between various constituents, and their properties, and the coke structure are examined.

Explorations in cokemaking research with a full scale coke oven model A. H. Brisse and J. G. Price (*Blast Furn. Steel Plant*, 1959, **47**, Dec., 1285–1290) An investigation is described of methods of minimizing the segregation of coal blend constituents within the coke oven, using a full-scale wooden test oven constructed at the Clairton Works of United States Steel Corporation. The investigation showed that a high degree of segregation was obtained by charging 3 in.×0 high-volatile coal with 1 in.×0 low-volatile coal; no significant segregation pattern was obtained when $\frac{3}{4}$ in.×0 high volatile and $\frac{1}{4}$ in.×0 low-volatile coals were mixed; and charges crushed to $\frac{3}{4}$ in.×0 showed a better random distribution of blends than either the 3 in.×0 or the $\frac{3}{4}$ in.×0 charges. Bulk density patterns were also examined and discussed.

The reactivity of coke. III. The influence of density of charging on coke reactivity at high temp. A. F. Boyer and G. Durand (*Chim. Ind.*, 1960, **83**, Feb., 223–231) Cokes in 400 kg lots were prepared at high temp. and porosity was reduced by increase of loading density, and reactivity is inversely proportional to apparent density.

Coking costs and coking time W. Ahlers (*Glückauf*, 1960, **96**, March 12, 341–347).

Utilisation of by-product fuels R. W. Worley and R. H. Gherst (*Iron Steel Eng.*, 1959, **36**, Aug., 67–71) Subjects discussed are: the use of blast-furnace and coke-oven gases as boiler and coke-oven fuels, and the possibilities of using blast-furnace gas as a gas turbine fuel for blast-furnace blowers.

The structure of coke oven tar E. W. Volkmann (*Fuel*, 1959, **38**, Oct., 445–468).

AIR POLLUTION AND SMOKE

Problems of air pollution in Germany H. Lent (*J. Inst. Fuel*, 1959, **32**, Oct., 485–491, discussion 492–501) Some mention of blast-furnace and steel plant emission is included.

Smoke measurement (*Nat. Coal Board Sci. Bull.*, 1958, Autumn, (7), 1–4). **Smokiness and Smokeless fuels** (4–6).

Balanced design in electrostatic precipitation R. L. Chamberlain (*Blast Furn. Steel Plant*, 1959, **47**, Oct., 1086–1089) Modern developments in precipitator design are set out and discussed.

Settling chambers for the collection of grit R. Jackson (*BCURA Bull.*, 1959, **23**, Aug.–Sept., Part II, 349–365).

Ways to save space in dust collector installations P. W. Zilliacus (*Foundry*, 1959, **87**, Oct., 222, 224–225) Examples are given of foundry experience with the Joy–Microdyne wet, inertial type dust collector, which is a highly compact installation.

TEMPERATURE MEASUREMENT AND CONTROL

Temperature measurement by thermocouples (*Inco–Mond. Mag.*, 1959, (11), 14–15) A review of pyrometers for all high-temp. purposes.

High temperature resistance thermometry (*NBS Techn. News Bull.*, 1959, **43**, Dec., 233) A Pt resistance thermometer for use up to 1063°C has been developed.

Determination of the surface temperature by infra-red photography U. Plöger (*Arch. Eisenh.*, 1960, **80**, Feb., 87–90) Taking as an example the temp. measurement of the roof of an OH furnace it is shown that infra-red photography is a very useful tool as it serves as a reliable indicator for the wear of the roofs of such furnaces. Details of the determination and the correctness of the indication are included.—T.G.

REFRACTORY MATERIALS

Refractories D. Dixon (*Vitr. Bull.*, 1960, **10**, Feb., 277–281, discussion 282–283) Refractory technology in recent years is reviewed. The needs of the enamelling industry are discussed in particular with a review of fusion furnaces.

Refractories keep pace with metals L. L. Gill (*Canad. Metalw.*, 1959, **22**, Dec., 30–31) The value of high-MgO refractories where high temp. are encountered is stressed and gunning mixes, ramming mixes, hydraulic setting castable refractories, and plastic fire-brick are described.—T.G.

Fundamental considerations of the use of refractory materials L. Dalmau Castells (*Acero Energ.*, 1957, **14**, Nov.–Dec., 37–51; 1958, **15**, March–April, 43–53; Nov.–Dec., 47–50, 53–59) In a general review of refractory materials, the author discusses the factors affecting the economic yield such as cost and working conditions, the physico-chemical properties of the refractories in use at Aviles, and the requirements of the specifications. In the final part, he deals with tolerances, means of rapid assessment of refractories, and their characteristics and the relationships between them.—P.S.

Plant for the production of basic refractories now in operation (*Blast Furn. Steel Plant*, 1959, **47**, Dec., 1283–1284) A description of the new Pascagoula, Mississippi, works of the Refractories Division of H. K. Porter Company Inc., is given. This incorporates a sea-water chemical plant for the extraction of the magnesia used in the works.

Refractory products F. Benoit–Cattin (*Arts Manuf.*, 1960, Jan., 39–40) A brief account of recent advances. (One of a series of review articles on ceramics).

Properties of unfired chrome–magnesite and magnesite–chrome bricks V. A. Rybnikov (*Ogneupory*, 1958, (7), 303–307) The properties and composition of these bricks, manufactured in the Soviet Union for OH roofs and walls are described.

Some metallurgical developments in China: Refractories research and utilization of mineral resources Hsun Li (*Refract. J.*, 1960, **26**, Feb., 32–33) Work on the utilization of complex iron ores, alumina bricks with reference to the use of fluoride-containing ores, and the OH production index is abstracted from an article in *Scientia Sinica*.

Refractories used in coke ovens J. Hodgson (*Refract. J.*, 1960, **36**, Jan., 14–18, 20) An account of the properties of silica, semi-silica, and fire clay and refractory cements.

Refractories used in coke-ovens J. Hodgson (*Gas World—Coking*, 1960, **151**, Jan. 2, 5–8, 10) A review. **Reflections on refractories** (3–4) Editorial comment on the above.

Basic refractories in sprung arch construction Harbison-Walker Refractories Co. (*Refract. J.*, 1960, **36**, Jan., 19–20) A review of US furnace construction.

Refractory brickwork in forge furnaces D. D. Carrington (*Refract. J.*, 1960, **36**, Jan., 9–11) The design of an oil-fired furnace is discussed.

Refractory products, their progress and use in the foundry J. Montagnier (*Fonderie*, 1959, (158), March 136–146) The properties and applications of a number of refractories are outlined, including SiO_2 and Al_2O_3 base materials of various types, chromite and basic materials, and carbon, silicon carbide, zircon, zirconia, plastic refractories, refractory cements, and monolithic refractories (23 refs).

Permeability of blast furnace refractories G. R. Eusner and J. T. Shapland (*J. Am. Ceram. Soc.*, 1959, **42**, Oct., 459–464) A permeameter is described for measuring gas flow through 2-in. cubes in three dimensions. Permeabilities of carbon, mullite, castable and high and super-high duty fireclay refractories are tabulated. There are usually wide differences in values along the three axes of the bricks.

Progress in aqueous slip casting of magnesia W. G. Garrett and L. S. Williams (*J. Am. Ceram. Soc.*, 1960, **43**, Feb. 1, 114) The progressive use of a more hydration-resistant fused grain (Thermal Syndicate Ltd, grade L), for extending the useful life of slip, is described.—S.H.–S.

Cell dimensions, solid solution, polymorphism, and identification of mullite and sillimanite S. O. Agrell and J. V. Smith (*J. Am. Ceram. Soc.*, 1960, **43**, Feb. 1, 69–76) A tabulated survey of X-ray, optical, and chemical data, and description of specimens. Single-crystal X-ray studies have revealed a new type of mullite (here called S mullite). Data are consistent with a solid solution ranging between $3Al_2O_3$–$2SiO_2$, $2Al_2O_3$–SiO_2, and $3(Al_{0.9}Fe_{0.1})_2O_3$–$2SiO_2$. The most reliable method of distinguishing mullite and sillimanite is shown to be measurement of cell dimensions. The cell dimensions of sillimanite vary only slightly.

A study of Shevaroy bauxites for the development of high alumina refractories: Part I. Factors affecting the preparation of grog H. V. Bhaskar Rao (*J. Sci. Ind. Res.*, 1959, **18A**, Dec., 549–598) Proportions of raw bauxite and china clay and firing temp. are worked out. Red bauxites are unsuitable but directions for producing refractories from white bauxite are given.

The role of refractories in steel's future W. S. Debenham (*Blast Furn. Steel Plant*, 1960, **48**, Feb., 169–173) Trends in steelmaking refractories consumption are considered against the changing pattern of steel production methods, in particular the increasing use of basic refractories in the open-hearth process, and the development of the use of oxygen in steelmaking.

Application of special refractory materials in the iron and steel industry J. D. McCullough (*Iron Steel Eng.*, 1959, **36**, Sept., 172–178) Topics discussed, with examples, include the use of castable refractories in blast-furnace repairs, and for hearths, walls, and roofs of various types of reheating furnaces.

The texture analysis of refractory structural materials L. Zagar (*Silicates Ind.*, 1959, **24**, June, 306–312) Methods of determining the mean distribution of porosity, and the relative amounts of 'permeable' and 'non-permeable' porosity are discussed, with an application to firebrick.

Some simple and complex forms of spalling D. Dixon (*Refract. J.*, 1960, **26**, Feb., 40–43) A description of the various forms of spalling and the terms applied to them. Boiler settings as well as furnace structures are described.

The reaction between molten steel and refractories. III. Observation of the interface of Al_2O_3–SiO_2 refractories and molten steel S. Minowa and M. Kato (*Rep. Govt. Ind. Res. Inst. Nagyoa*, 1960, **9**, Jan., 21–27) Chamotte refractory showed growth of acicular mullite. High Al_2O_3 walls showed colour changes depending on the kind of iron oxide.

IRON AND STEEL, GENERAL

The present world position in steel production A. Cresta (*Tecn. Indust.*, 1959, **37,** Nov., 1647–1652) [In Spanish] The author gives a brief review of the pre-1940 and post-1945 world conditions in steel production and follows it with a discussion of the L–D process and the present position. New developments offer interesting possibilities in solving the particular problems of steelmaking in the Argentine.

A survey of the development of Yugoslav smelting B. Djukic (*Met. Constr. Mech.*, 1960, **92,** Jan., 13–15) A brief summary of the smelters in operation with some production figures.—S.H.–S.

Ironmaking in India G. R. Bashforth (*Blast Furn. Steel Plant*, 1960, **48,** Feb., 189–193) Composition and location of raw materials, and ironmaking facilities and practice in India are described.

Inland Steel Company (*Iron Steel Eng.*, 1959, **36,** Sept., II–I38) The equipment and operation of the Indiana Harbor works of Inland Steel Company are described, with production data. A note on the Chicago Heights plant is also given.

Iron and steel in India. II. Raw materials and the location of industry G. R. Bashforth (*Brit. Steel*, 1959, **25,** Sept., 320–323, 326) The main Indian deposits of ores, fuels, fluxes, and refractories and their properties are described, and the location of the iron and steel industry is outlined.

A visit to Bhilai T. Chatterjee (*Sci. Eng.*, 1959, **12,** Nov.–Dec., 146–149) An account of a visit to the plant now under construction. One blast-furnace was lit in Feb. and steel production began in Oct.

Durgapur steel works (*Engineer*, 1960, **209,** Jan. 8, 55–56) Coke-ovens, boiler plant, and blast-furnaces are described. **Durgapur—a plant for India's growth** (*Engineering*, 1960, **189,** Jan. 29, 154–155) Finance and training are discussed. **Durgapur steelworks** (*Brit. Eng. Transport*, 1960, **42,** March, 280).

The Iron and Steel Institute in its new seat in the University City of Madrid (*Met. y Elect.*, 1960, **24,** Jan., 151–155) A summary of the organization and technical layout of the Inst. of I. and S. in the University City of Madrid.

An international view of research and development in the iron and steel industry A. H. Ingen Housz (*Cleveland Sci. Techn. Inst.*, 1959, Nov. 30, pp.27) The 6th Harold Wright lecture. International co-operation is research and the work of the technical committee are discussed and flame research, pulverized fuel, the low-shaft furnace at Liège, rolling experiments, and silica bricks for OH roofs are mentioned as examples. New subjects for research are mentioned.

2nd Dempster Travelling Fellowship report. 2: Ferrous metal industries T. Ward (*Inst. Gas Eng.*, 1959, *25th Autumn Research Meeting*, Nov., 17–18, 7–18) The fellowship surveyed Continental uses of gas in industry. OH, billet melting, forging furnaces, and heat-treatment uses are outlined and plant is illustrated.

The possibilities for automation in the iron and steel industry offered by electronics B. Plettner (*Stahl Eisen*, 1960, **80,** April 14, 508–513) The possibilities offered by the employment of analogue–digital analysers towards automation on a broad basis in iron and steelworks are discussed. Programming as a further means in this direction is also mentioned.

Consultation in the steel industry in the socialist economy W. Küntscher and P. Holtzhaussen (*Neye Hütte*, 1960, **5,** Feb., 60–61) Functions of the East German 'Stahlerat-ungsstelle' are outlined. This is an information and consultation centre for various aspects of iron and steel manufacture and applications, including standardization.

The iron ore base of the USSR ferrous metallurgy and the path of its growth in 1959–65 I. Bardin, E. Moskal'kov, and I. Shapiro (*Planovoye Khozyaystvo*, 1958, (12), 16–27; *JPRSL*–1572–*D*; from *US Techn. Transl.*, 1959, **2,** Nov. 6, 668).

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG-IRON

A new blast furnace of 9 m hearth diameter C. Winters (*Stahl Eisen*, 1960, **80,** April 14, 465–473) The new blast-furnace of the August–Thyssen–Hütte at Duisburg–Hamborn is described. It has a hearth diameter of 9 m and a capacity of 1424 m^3. The output is 2000 t/24 h at a coke consumption of 660 kg/t iron. The blast can be preheated to ~1000°C. It was found that easy operation and low flue dust quantities (about 70 kg/t iron) can be achieved if the burden is charged in such a manner that the fines go towards the outside. Charging equipment to obtain such a distribution of the burden has been developed. Another feature of the new furnace is that flue-gas cleaning is done electrostatically.—T.G.

No.1 blast furnace commissioned at Durgapur (*Brit. Steel.*, 1960, **26,** Jan., 12–13) Details of the furnace are given and its part in the plan for the complete steelworks is outlined.

Low-load blast furnace for iron smelting P. Vajragupta and P. Chotinuchit (*Iron Steel*, 1960, **33,** Feb., 69–70) A description is given of a proposed modified top in a blast-furnace, so designed that the load on the materials at the bottom is half the normal value, without reducing the standard furnace height.

Stock distributor for blast furnaces A. S. Ayukov (*Russian Patent No.*100, 875, Class 18a 6_{01}, 1959, Jan. 14) Design is simplified and unnecessary rotation of the small bell with its hopper avoided by the means described.

Experience with self-fluxing sinter at the Steel Co. of Canada, Limited J. S. McMahan (*Iron Steel Eng.*, 1959, **36,** Aug., 108–126) The results of a trial programme using self-fluxing sinter at the B furnace of Steel Company of Canada are described in great detail. The trial period lasted from Nov. 1957 to April 1958, and the results obtained are assessed and discussed, mainly from the point of view of increased production rates obtained.

Investigations of the reduction process on a bed of ore S. I. Privalov, V. N. Timofeev, and B. A. Bokovikov (*Stal'*, 1960, (1), 5–14) A stationary-bed model furnace 450 mm high and 80 mm dia. was constructed and sampled at 40 min. intervals while fired with producer gas from a unit large enough (400 mm dia.) to supply gas constantly during the run. The furnace was charged with 5–24 mm dia. ore pellets and heated in a muffle. Reduction at each level was estimated from gas composition and the values were referred to the counter-current process of the blast-furnace. A further study at higher temp. taking into account the CO_2+C reaction is to be made.

An investigation of the movement of pig iron and slag in the blast furnace hearth N. N. Babarykin, A. A. Zborovskii, A. I. Potapov, and E. I. Rabinovich (*Stal'*, 1960, (1), 19–23) A tracer study was carried out with ^{32}P and ^{59}Fe. It was found that there was no considerable degree of mixing during the accumulation of metal or slag which accumulate and are tapped in substantially separate layers. The conditions in the stack and hearth are discussed.

The distribution of the burden in the blast furnace and factors affecting the distribution G. Heynert, F. Toussaint jun., H. Willems, and G. Quade (*Stahl Eisen*, 1960, **80,** April 14, 473–483) The mechanisms involved in the gravity feed of the burden from a slope chute were studied on models simulating blast-furnace conditions. The studies were supplemented by trials in the blast-furnace. The results are presented in many graphs. It was found that by using the knowledge obtained in the tests, furnace practice could be altered so that the coke consumption was reduced, the quantity of flue dust decreased, and the formation of scaffolding avoided. The means to achieve this are discussed in detail. The paper is followed by a lengthy and very interesting discussion (31 refs).—T.G.

Results of temperature measurement in the hearth through the slag notch V. K. Kropotov (*Stal'*, 1960, (2), 107–110) Conditions inside the blast-furnace are discussed and temp. fluctuations as measured through the slag notch are considered in regard to the processes periodically taking place.

Analysis of the operation of blast furnaces with stack coolers of various constructions S. M. Andon'ev, G. A. Kudinov, and O. V. Filip'ev (*Stal'*, 1960, (1), 23–28) It is concluded that the best type consists of vertical plate peripheral coolers in continuous rings in close contact with the furnace shell.

Increased production obtained from automatic regulation of blast furnace Hagan Chemicals and Controls Inc. (*Blast Furn. Steel Plant*, 1959, **47,** Oct., 1081–1082) Automatic regulation of blast furnace top pressure has increased iron production without greater flue dust losses. The Hagan top-pressure control system installed at Allan Wood Steel Co., Conshohocken, Pa., is described.

How to boost blast furnace efficiency Alan Wood Steel Co. (*Steel*, 1959, **145,** Nov. 9, 162) A system for automatically controlling blast furnace high top pressure is described. A 'blocking valve' ensures that the two regulating valves are not influenced by surges during bell movements.—D.L.C.P.

New blower station at Port Kembla A. A. Taylor (*BHP Rev.*, 1959, **36,** June, 18–21) An illustrated account of the blast-furnace blowing plant using axial-flow turbo-blowers.

The production of gases for the reduction of iron ore H. W. von Gratkowski (*Stahl Eisen*, 1960, **80,** March 31, 397–407) The author reviews the possibilities and practices used for the production of gases, for the reduction of iron ore, from solid, liquid, and gaseous fuels with special emphasis on the methane nitrogen contents which should be low (29 refs).—T.G.

Gas purification for blast furnaces operating at high pressure and with enriched blast D. K. Myzenko, V. M. Pomazuev, and M. S. Mironchik (*Stal'*, 1960, (2), 182–186) A scrubber unit is described with an account of its development and early troubles. Ferrosilicon production gases are more troublesome to purify and an electrostatic system is necessary.

The use of radioisotopes in a blast furnace A. E. Frey (*Blast Furn. Steel Plant*, 1960, **48,** Feb., 165–168) ^{60}Co sources were placed in several positions in a monolithic patch to a blast-furnace throat, to determine the life of the patch. Counters, enclosed in a stainless steel shell, were mounted near the surface of the shell at suitable positions. Readings are taken before each cast, and the test is still in progress.

Continuous pre-refining of iron in the blast furnace runner by the injection of pure oxygen through porous tiles P. Leroy and R. Simon (*Rev. Mét.*, 1960, Jan., 21–27) Method of installing the tiles and oxygen equipment and recent results are given, and the efficiency and economics of the process are discussed. Advantages include Si removal without the evolution of the brown fumes usually obtained by the use of oxygen.

Non-traditional processes for iron-ore reduction A. Scortecci and A. Palazzi (*JISI*, 1960, **195,** July, 267–278) [This issue].

Electric pig irons G. Zuliani (*J. Four Elect.*, 1959, **64,** (3), 135–136) The slag conditions and energy consumption in the manufacture of hematite iron, and the energy consumption in the manufacture of high-Si pig iron are discussed.

PROPERTIES, TREATMENT, AND USE OF SLAG

Viscosity and structural elements of molten aluminosilicates: $CaO–Al_2O_3–SiO_2$ slags between 1600 and 2100°C P. Kozakevitch (*Rev. Mét.*, 1960, **57,** Feb., 149–160) Results obtained using a rotating cylinder viscometer are reported for the ranges $0<Al_2O_3<100\%$, $0<SiO_2<70\%$, $0<CaO<60\%$, and the ternary diagrams are discussed (23 refs).

Determination of ignition loss in Portland blast-furnace slag cements B. Chaiken (*ASTM Bull.*, 1959, (238), May, 53–57) Modifications of the normal test are necessary owing to the presence of oxidizable sulphides.

The Rilem–Cembureau method for testing the strength of cement R. Dutron (**Zement-Kalk–Gips*, 1960, Feb., 64–70) The development of the test is described. A jolting table is used to form specimens 4×4×16 cm using a standard sand. Reproducible values for flexural and compressive strengths can be obtained.

The testing of cement by the Rilem–Cem method F. Keil and H. Mathieu (**Zement-Kalk–Gips*, 1960, Feb., 70–78) Types of cement, including blast-furnace cements were tested and a standard test method was evolved

Compressive and flexural strengths are measured and the test certificate is specified also.

DIRECT PROCESSES

Will new iron-making methods cut blast furnace operations G. J. McManus (*Iron Age*, 1959, **184,** Oct. 8, 114–117) A review is given of direct reduction processes in commercial and pilot plant operation. Several processes are considered to be technically sound and commercially profitable for outputs around 500 t per day. A table of 24 processes is included.

Production of iron and steel by the Strategic-Udy process M. C. Udy and M. J. Udy (*AIMME Elec. Furn. Steel Conf. Proc.*, 1958, **16,** 220–229) A description is given of the Strategic-Udy process for the production of iron or steel. Particular reference is made to the prototype plant operated by the Strategic-Udy Company; the plant is described and typical operating results are given.—G.F.

Sponge iron R. Lawrence jun. (*AIMME, Elec. Furn. Steel Conf. Proc.*, 1958, **16,** 242–243) A discussion is presented of the 200-t HyL direct reduction sponge-iron plant at Hojalata y Lamina SA at Monterey, Mexico.—G.F.

New: making iron in a fluidized bed R. A. Labine (*Chem. Eng.*, 1960, **67,** Feb. 8, 96–99) A process flowsheet.

Republic reveals strip process at new research centre dedication (*Iron Steel Eng.*, 1959, **36,** Aug., 133–134) A description is given of the production by Republic Steel Corp. of steel strip directly from iron ore without melting. The ore is reduced to Fe powder, which is compacted by rolling, then reheated and finally rolled into finished strip.

PRODUCTION OF STEEL

Ferrous metallurgy W. C. Leslie (*J. Met.*, 1960, **12,** Feb., 159) A review of recent process, with reference to the addition of small amounts of Nb to semi-killed low- and medium-C steels, advantages of open coil annealing, and recent work on the mechanical properties of high-purity Fe–C alloys.

Recent trends in iron and steel technology B. R. Nijhawan (*Blast Furn. Steel Plant*, 1959, **47,** Oct., 1057–1060) A general review of the use of O_2 in the side-blown, basic-Bessemer and LD converters and the OH furnace, with reference to the refining of high-P irons; the OCP and 'buffer-slag' processes, is given.

Japan's iron and steel industry 1959 T. Shimamura (109–114). **Technical development of iron and steel making in Japan.** This is a translation of Chap. III of a book, Tekko Keizai Ron, dated Dec. 20, 1958. It is a very brief account of developments introduced by the various steel firms. **Part III. Modernization by steelmakers** (166–191) Reviews of improvements by the Yawata Co., Fuji Co., Nippon Kohan Kabushiki Kaisha, Sumitomo Metal Industries, Kobe Steelworks Ltd., and Kawasaki Steel Corp.

Potential for oxygen in steelmaking E. C. Wright (*Met. Prog.*, 1959, **76,** Sept., 101–107) Developments in the use of oxygen in the blast-furnace, electric steelmaking, open-hearth practice, the basic Bessemer converter, and the LD furnace are discussed.

Oxygen as an indispensable element in modern iron and steelmaking practice A. Saigueiro y de Spinola (*Cien. Tecn. Solda.*, 1959, **9,** Nov.–Dec., **2,** 2392, 1–13) A description is given of processes which convert iron to steel with the use of O_2 in particular the LD, LDP, Kaldo, Rotor, and OLD processes. Reference is made to the Russian process for refining iron by inserting oxygen lances into the blast-furnace runner.

Considerations of the importance of the degree of purity and quality of steel in the modern machine and structural industries B. Matuschka (*Inst. Hierro Acero*, 1959, **12,** Oct.–Dec., 288–294) Increasing production and modern developments have led to more exacting demands for quality and the author discusses particular applications with reference to the effect of residual elements and modern steelmaking methods.—P.S.

Reactions between magnesium oxide and molten iron under reduced pressure K. Brotzmann (*Arch. Eisenh.*, 1960, **31,** Feb., 67–81) The author reviews published information on the stability of MgO in the presence of molten iron and reports experiments on the reactions of molten iron in MgO crucibles at very low pressure. The water content of the crucible has a major effect. The crucible dissolves large quantities of ferrous oxide at high rates, but it liberates it quickly also. However, in the production of high-purity iron in MgO crucibles *in vacuo*, the pressure in the reaction zone is so high that there is no risk of a reaction between melt and crucible taking place, i.e. no increase in the O_2 content of the high-purity iron will occur when the iron is processed in MgO crucibles (18 refs).—T.G.

The Bessemer's progress S. G. Cope (*Murex Rev.*, 1960, **2,** (21), 1–37) A review of the process with special reference to oxygen steelmaking including the LD and Kaldo processes.

The manufacture of basic Bessemer steel with a small excess of lime by the R.T.M. process A. Latour and L. Heinen (*Radex Rund.*, 1959, (4), 565–579) In the RTM process (RTM = Röchling–Thomas–Mahl) ground basic slag is injected into the converter iron either through the blast or by injecting through an oxygen lance from above. Consumption of burnt lime is reduced by 25%, and the P_2O_5 content of the slag and its citrate solubility are increased and its Fe content diminished. N_2 content of the steel is also decreased, steel output is increased and blowing time shortened. Operational details are given.

The basic Bessemer steelworks of the Hüttenwerk Salzgitter AG G. Wittek (*Demag Nachr.*, 1959, (157), 1–7) An illustrated account.

The use of natural gas in smelting (*Echo Mines*, 1959, Oct., 567) A note on the use of natural gas to economize coke in the HyL process, and the possibilities of its use in electric furnaces.

French converter process produces quality steel Soc. Usinor (Denain) (*Steel*, 1960, **146,** Feb. 1, 92–94) The French IRSID oxygen-lime blast steelmaking process is described.

Simplified calculation of effects of oxygen blowing rates G. W. Healy (*AIMME, Elec. Furn. Steel Conf. Proc.*, 1958, **16,** 252–258) The author rearranges the heat balance equation for the oxidizing period in stainless steel melting, thus permitting rapid calculation of the effects of composition and temp. before blowing, O_2 rate and furnace size on the carbon content, metallic oxidation, and temp. after blowing. A number of blowing practices may thus be surveyed before actual trials.—G.F.

Acme Steel automates oxygen converters (*Steel*, 1959, **145,** Dec. 28, 80) A brief sketch of the control system.

The metallurgy of the oxygen steel-making processes E. Plöckinger and M. Wahlster (*Stahl Eisen*, 1960, **80,** March 31, 407–416) The metallurgical processes involved in steelmaking by O_2-blowing were studied in a 3-t capacity LD research converter with particular emphasis on the course of refining with respect to C, Si, Mn, P, and S for different practices. In spite of large variations in refining the composition of the final product, if the carbon content is reduced below 1%, is the same for all practices. The main variations were in the cooling, i.e. with ore and scrap; puddle bars were also used. The O_2 jet stirs the bath with such efficiency that the theoretical equilibria were almost attained in practice.—T.G.

L–D process for making basic oxygen steel E. J. Prince (*Iron Steel Eng.*, 1959, **36,** Sept., 185–186) A brief review of the main features of the LD process and its modifications; with a discussion of its economic advantages compared with a new OH shop.

Basic oxygen furnace construction and operating data D. R. Loughrey (*Ind. Heat.*, 1959, **26,** Sept., 1816, 1818, 1820, 1822) The article deals in detail with furnace construction, describes operating procedure, and gives data accumulated since the start of basic oxygen operations at the Jones and Laughlin Steel Corp.

Research into steelmaking processes being conducted at South Works (*Blast Furn. Steel Plant*, 1959, **47,** Aug., 849–851) A brief account of pilot-scale plant demonstrated at the South Works, Chicago of United States Steel Corporation, namely an experimental OH furnace where the interior is viewed by television, multiple vacuum casting, and a consumable electrode furnace.

Substitution of briquetted millscale for open hearth ore A. M. Kim and V. Ya. Gusev (*Stal'*, 1960, (2), 123–124) Millscale added to the heat often failed to penetrate the slag so briquetting equipment was installed. Spherical or cube briquettes sink quicker and react less with the slag. The use of scale in this way improves S and P removal and saves bauxite.

Description of the Loftus open-hearth furnace F. Gautier (*Rev. Mét.*, 1959, **56,** Aug.–Sept., 162–174) The shell construction, refractories, burners, and other equipment, including regulating appliances of this type of furnace, are described, recent improvements are outlined and some results obtained are reported.

Contribution to the discussion on the paper by K. F. Lüdemann on 'The influence of high hearth loads and increasing proportions of stahleisen in the charge on the operating conditions of the Maertz type open-hearth furnace' H. Leopold (*Neue Hütte*, 1959, **4,** Aug., 502) It is pointed out that Lüdemann (1959, **4,** April, 198–207), discussed furnaces with a useful hearth area of only 47·3 m^3, whereas hearth areas of modern furnaces with a similar capacity of 160 tonnes are often substantially larger. Together with suitable design and the use of high-calorific fuels, the effects of high proportions of solid stahleisen in the charge can be lessened.

All basic open hearth boosts Keystone's output Keystone Steel & Wire Co. (*Steel*, 1959, **145,** Dec. 14, 102–104) A 175-t OH furnace of novel design is described. Front and back walls slope inward to the roof which has a span of less than 12 ft. Front and back walls and roof are of suspended brick construction. There are three checker chambers.—D.L.C.P.

The use of pretreated pig iron in the open hearth furnace Ya. A. Shneerov, V. V. Leporskii, A. G. Derfel', A. G. Kotin, M. T. Bul'skii, and A. G. Alimov (*Stal'*, 1960, (1) 32–35) Trials with pig iron previously blown with a mixture of steam and O_2 gave increased furnace rate and reduced fuel consumption.

Power input control in electric arc furnaces J. Ravenscroft and L. McGee (*JISI*, 1960, **195,** July, 340) [This issue].

Experience with ladle degassing C. W. Finkl (*AIMME, Elec. Furn. Steel Conf. Proc.*, 1958, **16,** 93–102) The author describes the experience of A. Finkl & Sons Co. in ladle degassing of Cr–Ni–Mo steel. The effects of slag volume, Al additions, and purging with He during degassing, are evaluated. For the highest efficiency of H_2 removal, the ladle slag must be removed and the vacuum treatment combined with purging.—G.F.

Degas steel with lithium A. J. Nimeth (*Iron Age*, 1959, **184,** No.25, Dec. 17, 168–169) A technique has been developed by Jones & Laughlin for eliminating gas from stainless steels. This involves the use of encapsulated Li coupled with argon purging in the melting furnace with a further addition of Li to the ladle. The Li vapour mechanically scavanges H_2 and other gases while Li_2O can dissolve many refractory inclusions.—A.G.

The uses of niobium in iron and steel manufacture (*Génie Civil*, 1959, **136,** Dec. 15, 486–488) The origins, metallurgy, and properties of Nb, its uses in steel manufacture, with reference to corrosion-resisting, austenitic, and low carbon steels, and a new series of uses in the last-named by the Great Lakes Steel Corp. USA, are described.—S.H.–S.

Ultrasonic vibrations refine grain size D. H. Lane, J. W. Cunningham, and W. A. Tiller (*Met. Prog.*, 1959, **76,** Sept., 108–110) The technique used in the grain refining of 12-in. diameter ingots made by consumable-electrode melting using ultrasonic vibrations is described, and ingot structure is illustrated and discussed.

How method lifts ingot quality Carpenter Steel Co. (*Iron Age*, 1959, **184,** Nov. 19, 128–129) The Mel–Trol (melting control) system of quality control of melting variables is outlined. Scrap charge analysis with classification into six grades for making 403 steel alone, frequent spectrochemical analysis of the heat temp. control and a new mould design give ingots of high quality and uniformity.

Effect of the rate of rise of rimming steel in moulds on the surface quality of slabs A. T. Peters (*Trans. Met. Soc. AIME*, 1959, **215**, Oct., 877–878) Data showing surface quality of rimming steel slabs poured at different rates are presented, quality being examined in relation to the incidence of cracks, scabs, and checking.

Continuous casting of steel H. Hofmeister (*Demag Nachr.* and *Demag News*, 1959, (156), 27–31) An outline of the vertical continuous casting process is given, with design and operational details of the eight-strand plant installed by DEMAG in Italy.

Continuous casting at Terni M. Signora and R. Cardano (*JISI*, 1960, **195**, July, 253–260) [This issue].

Horizontal continuous casting plant for quantity steels R. Dawirs (*Stahl Eisen*, 1960, **80**, March 31, 444–446) As the usual vertical continuous casting plant is limited in throughput the attempt was made to cast horizontally to fulfil the requirements for large-scale production. The principles of horizontal continuous casting are briefly described, a new 12-m long horizontal mould is illustrated. A table is included in this report listing the known continuous steel casting plants in the world.—T.G.

The efficiency of continuous steel casting at a new plant G. V. Vitin (*Stal'*, 1960, (1), 84–88) A statistical discussion with flow diagrams. The planning of a new installation with an output of $3{\cdot}5 \times 10^6$ t is considered, with an estimated net saving of 75×10^6 roubles and 570 less operators, with an increase of efficiency of 24%.

Crystallization of iron during continuous casting A. D. Popov (*Lit. Proizv.*, 1959, (12), 27–28) In continuous casting the determination of the main parameter, the speed of withdrawal, is of paramount importance. This depends to a large extent on the crystallization constant, on the thickness of the component, and on the depth of the liquid phase. From crystallization constants taken from actual measurements formulae have been deduced so that the speed of withdrawal can be adjusted for different measurements.

Contribution to the study of the structure and mechanical properties of continuously cast steel G. Wilz and M. Jaspart (*Rev. Mét.*, 1960, **57**, Jan., 45–62) The solidification structure of a 240 mm² section is examined, and compared with that of billets produced in the normal way. It is shown that segregation is much less and structure is finer and more homogeneous. The results of forging tests were satisfactory.

Influence of cooling and withdrawal rate in continuous casting on the homogeneity of unalloyed structural steels F. Leitner and R. Rosegger (*Radex Runds.*, 1959, (4), 590–599) Trials in which cooling and withdrawal rate were varied in the continuous casting of electric furnace steel showed that the formation of internal and edge cracks in good mould practice were due to non-homogeneous and severe cooling, while shrinkage cavities are attributable to rapid casting with unsuitable cooling. Surface lapping and similar defects are caused by unsatisfactory mould behaviour, slow casting, or a casting temp. which is too low.

Structural flaws in low-carbon steel ingots enhanced by hot plastic working F. Borelli and G. Testero (*Met. Ital.*, 1960, **52**, Jan., 1–7) On surfaces obtained by cutting or trimming steel plates using cold shears, irregularities often occur which at first sight appear to be slight interruptions in the continuity of the metal. It was found, however, that among these is a special type where there is no interruption in the continuity of the material. This is a special micrographic structure caused by the segregation of non-metallic constituents. Equipment for the detection of these flaws, such as by magnetic powders and ultrasonic tests, is described.

Is ingot peeler practical in American Steelmaking? Societa Generale per l'Industria Metallurgica e Meccanica (*Steel*, 1960, **146**, Jan. 25, 74) The value of a giant milling machine that peels scale and surface flaws from hot ingots is considered; the machine was developed in Italy. About ⅛ in. can be removed from each face of square ingots up to 5-t size, at 2200°F. By avoiding the necessity to cool ingots for surface treatment, heat is saved and internal cracking is prevented. There is doubt that the machine will be adopted for large carbon steel ingots, but it should be useful for smaller ingots of aluminium-killed or alloy steels.—D.L.C.P.

An investigation on the weldability of primary and secondary pipe cavities in rail steel ingots cast in conical moulds without hot-tops W. Hansel and B. Prusinski (*Hutnik*, 1959, **26**, (12), 482–496) The authors justify the use of moulds tapering towards the top and without hot-tops. By using this method, output reaches a maximum and to ensure a satisfactory quality it must be remembered that a clean shrinkage cavity is weldable and weldability depends mainly on the way the material is worked plastically. The deciding factors are: the correct freezing of the top of the mould which ensures that no O_2 enters as the cavity develops. The temperature at which rolling commences should be at least 1200°C and the time for which the ingot is heated is also important. Care should be exercised to roll the ingot correctly. With a Si content of from 0·15 to 0·18% in the casting, weldability of the cavity is at its best. The article contains numerous tables and drawings.

Low carbon steel for the production of bimetallic strip A. A. Kiselev and G. F. Marchenkovskii (*Stal'*, 1960, (2), 121–123) Low-C Armco-type iron was made into bimetallic strip with Al–Sb–Mg alloy to replace lead-bronze in bearings. Depending upon degree of oxidation the steel may crack or suffer from laminations. These can be avoided by careful attention to melting and pouring.

PRODUCTION OF FERRO-ALLOYS

The role of the National Metallurgical Laboratory in the development of a ferro-alloy industry in India P. P. Bhatnagar and B. R. Nijhawan (*Trans. Indian Inst. Met.*, 1959, **12**, Sept., 257–271; discussion 271) The beneficiation and smelting of Indian ores using novel processes are described for the production of Fe–Mn, Fe–Cr, and Fe–V.—A.D.H.

The production of ferroalloys in a pilot plant A. Banerjee and S. Visvanathan (*Trans. Indian Inst., Met.* 1959, **12**, Sept., 247–256) Small scale production of Fe–W, Fe–Cr, Fe–V, Fe–C–Ti, and Fe–B at Jamshedpur in direct arc furnaces is described.—A.D.H.

Experience in smelting ferromanganese in a large blast furnace L. G. Shunakov and G. I. Chasovitin (*Stal'*, 1960, (2), 104–107) Trials with Chiatura ore showed that in a 1000 m³ furnace, acid slags, high blast temp. and high top pressure give good results.

Metallurgy of ferromanganese production in the blast furnace N. J. Wadia and V. G. Paranjpe (*Trans. Indian Inst. Met.*, 1959, **12**, Sept., 273–298, discussion 298) Slag-meta reactions and calculations of the burden are reviewed (28 refs).—A.D.H.

The production of high carbon ferromanganese in the electric furnace C. A. Ganesh and D. D. Bhuptani (*Trans. Indian Inst. Met.*, 1959, **12**, Sept., 205–218, discussion 218–219) Practice at the Joda Ferroalloys Works of the Tata Iron and Steel Co., is described with reference to the conductivity of the charge and the effect of slag basicity on the reduction of Mn and Si.—A.D.H.

Utilisation of low-grade manganese ores for production of standard ferromanganese by a Duplex smelting method R. D. Lalkaka (*Trans. Indian Inst. Met.*, 1959, **12**, Sept., 235–246) The process consists of (*a*) smelting ore containing 30%Mn and 21%Fe to produce spiegeleisen (12%Mn, 0·2%P) and slag containing 54%Mn and (*b*) the slag from (*a*) with further low grade ore was smelted to yield ferro-manganese (76%Mn, 0·1%P). The operations were carried out in a 2000 kVA prototype submerged arc furnace and the design of a plant suitable for commercial exploitation of the process is described.—A.D.H.

Manufacture of ferrosilicon alloys E. J. Davis and A. D. Gate (*AIMME, Elec. Furn. Steel Conf. Proc.*, 1958, **16**, 15–24) The Globe plant of Interlake Iron Corp. produces 6–10%Fe–Si in a blast-furnace, and 14–98%Fe–Si in a submerged-arc electric furnace. Descriptions are given of both processes.—G.F.

Selection of a method of ferrosilicon production A. A. Frolov (*Stal'*, 1959, (910), 917–919) A cost comparison showing the advantage of electric over blast-furnaces for lean grades of Fe–Si with special reference to coke rate. 1958 figures are used.

Production of crystalline silicon in a rotating bath furnace B. V. Voskresenskii and M. A. Ryss (*Stal'*, 1960, (1), 51–53) Preliminary trials suggest that rotation of the bath is useful in preparing a number of difficult silicon alloys. Full scale trials are needed.

Control of quality in ferroalloy manufacture A. F. Sprankle (*AIMME, Elec. Furn. Steel Conf. Proc.*, 1958, **16**, 34–41) The author describes the basic manner in which quality control is obtained in the manufacture of ferroalloys. He considers control of the raw materials and of the smelting operation, inspection of the finished product, and overall technical control of the plant.—G.F.

Casting ferroalloys E. T. Johnson (*AIMME, Elec. Furn. Steel Conf. Proc.*, 1958, **16**, 27–32) The author discusses some of the basic procedures adopted in the casting of ferroalloys, and outlines the problems involved. He deals particularly with the basic alloys of Si, Cr, and Mn produced in the submerged arc furnace.

FOUNDRY PRACTICE

Foundry industry in Great Britain and some general trends of development R. M. Krishnan (*NML Tech. J.*, 1959, **1**, Nov., 5–15) A review of recent trends shown by the foundry industry in Great Britain.—T.G.

The foundry industry of the United Kingdom: its organization and capacity A. R. Parkes (*Found. Trade J.*, 1959, **107**, Oct. 22, 343–348) A brief account of the B.N.F.M.R.A, BSCRA, Institute of British Foundrymen and other bodies, the Foundry Trades' Equipment and Supplies Association, National Society of Master Patternmakers, and the contributing Associations, educational bodies, and the technical press.

"Welcome on the mat" at London area foundries (*Found. Trade J.*, 1959, **107**, Oct. 22, 349–359) The foundries to be visited by the IBF are briefly described: British Bath Co. Ltd., K. & L. Steelfounders & Engineers Ltd., Ford Motor Co. (Dagenham), Langley Alloys Ltd, Le Grand Western Foundries Ltd, and G. D. Peters & Co. Ltd.

Alvechurch open days. Ceremonies for new foundry atmospheres building and cupola plant (*Iron Steel*, 1959, **32**, July–Aug., 373–374) A description of the new buildings recently inaugurated at the BCIRA premises at Bordesley Hall.

Ingot mould foundry (*Iron Steel*, 1959, **32**, July–Aug., 397–398) The £2 million plant opened by Guest Keen Iron and Steel Co. Ltd, at Dowlais is described and illustrated.

Papers on the mechanized foundry No.11. Examples of foundries (*Fond. Ital.*, 1960, **9**, (12), 19–22) The layout and equipment of typical mechanized foundries for the production of large and medium castings are described.

A visit to LFM foundry (*Mod. Cast.*, 1960, **37**, Jan., 41) A very brief description of America's largest electric steel foundry.

Preventive maintenance speeds production N. Luther (*Foundry*, 1959, **87**, Oct., 96–99) The programme adopted and economies achieved at the grey iron foundry of Pontiac Motor Division of General Motors Corp. are described.

Moving foundry materials on oscillating conveyors G. Morden (*Mod. Castings*, 1959, **36**, Oct., 35–37) The conveyor of perforated metal troughs is used for conveying screening and sorting and cooling of hot metal and sand in a limited floor space.—A.D.H.

New design for foundry conveyor Conveyor and Shotblast Co. Ltd (*Light Met.*, 1959, **22**, Oct., 230) A system of trolleys running in a cruciform box-shaped channel is described.

A contribution to the study of the economic efficiency of trucks running on the foundry floor R. Pokorny (*Giesserei*, 1959, **46**, Sept. 10, 524–528) With practical examples.

Platinum thermo-couple–platinum rhodium for measuring foundry temperatures E. R. Perry (*Fond. Ital.*, 1960, **9**, (12), 15–18) Their

use in controlling melting conditions in the production of ferrous and non-ferrous alloys is described.

The performance of centrifugal moulds A. Königer (*Giesserei*, 1960, **47,** Feb. 11, 70–74) The stresses set up during casting in centrifugal steel moulds are discussed. These stresses, tensile and compressive, give rise to crack formation in the interior of the mould after relatively few castings thus rendering it useless. Studies on the life of the moulds showed that steels of a high notch-impact strength which were at the same time highly thermal-shock-resistant showed a very much longer life than the steels used hitherto. The plot of number of castings/notch-impact toughness is not a straight line, but is somewhat curved, thus indicating this trend.—T.G.

Saving costs in foundry fettling S. M. Gray (*Eng. Found.*, 1959, **25,** Sept., 52–55) Variable factors are named and their reduction outlined. Grinding wheel economics are considered.

Some casting defects—their causes and cures J. L. Francis and S. J. Rogers (*Brit. Found.*, 1959, **52,** Dec., 529–541) The following subjects are discussed; porosity, shrinkage, unsuitable sand properties, inverse chill, use of chills and chaplets, and trace elements in cast iron.—A.D.H.

Sand inclusions in thin-walled iron castings, and their effect on enamelling P. Göbbels (*Found. Trade J.*, 1960, **108,** Jan. 14, 37–40) Holes in thin-walled castings may be caused by reaction of the molten Fe with the mould particularly when silica sand has been used. In shell-moulding this porosity and hole formation can be avoided by sealing the mould surface.—T.G.

Safety and housekeeping in foundries H. H. Tranter (*Brit. Found.*, 1959, **52,** Dec., 549–554) The hazards peculiar to foundries are discussed and suggestions made for reducing the incidence of accidents.—A.D.H.

VACUUM METALLURGY

80-ton electric arc melting furnace expedites vacuum casting of 110-inch ingots United States Steel Corp. (*Ind. Heat.*, 1960, **27,** Jan., 87–88) Three 80-t heats are poured into the vac. chamber containing the mould. The ingots are virtually free from H_2, and are forged and machined into steam-turbine rotors.—K.E.J.

On the technology of vacuum melting of metals and alloys: practical use of the vacuum furnace for refractory metals A. V. Emyashev (*HB*-4365; trans. from *Primenenie Vakuuma u Metallurgii*, 1958, 54–61; from *US OTS, Techn. Trans.*, 1959, **2,** Dec. 4, 819) Russian equipment is reviewed and a 110-lb furnace for melting steel, its operation and performance described. Refractories are discussed and production of crucibles, temp. measurement, sampling, and avoiding hanging of the charge are considered.

Degassing of steel by vacuum casting for the production of castings and forgings V. Scalise, A. De Negri, and V. Piccardi (*JISI*, 1960, **195,** July, 260–266) [This issue].

The metallurgy of iron in a high vacuum W. A. Fischer (*Arch. Eisenhütt.*, 1960, **31,** Jan., 1–9) Theoretical. Formulae are derived for the evaporation of iron in a high vacuum in the presence of C, O_2, N_2, H_2, S, P, As, Mn, Si, Cr, Ni, Co, Sn, Mo, W, Ta, and Ti. Reactions that may take place with the mould material are also discussed. Finally the pick-up of O_2 from the mould materials is mentioned (40 refs).

Vacuum treatment of molten steel in Germany P. J. Wooding and W. Sieckman (*Met. Prog.*, 1960, **77,** Jan., 116–122) The Dortmund-Hörder process, in which successive portions of liquid steel are forced into an evacuated vessel by atmospheric pressure, is described, particular reference being made to the results of trials which showed that H_2 content can be reduced in the presence of Cr. Rolling properties of the vacuum-treated steel, and operating costs are discussed.

The diecasting of steel under vacuum V. M. Belov and S. A. Kazennor (*Metalw. Prodn.*, 1959, **103,** Nov. 6, 1793–1795, from *Proizv. Lit.*).

Vacuum treatment of metals: Application in the steel industry (*Iron Coal Trades Rev.*, 1959, **179,** Dec. 25, 1183) A brief review in general terms.

Vacuum pouring of ingots for heavy forgings. III J. H. Stoll (*Ind. Heat.*, 1959, **26,** July, 1363–1370) Data are given for the properties of vacuum-poured as compared with normally poured steel. The main improvements are in ductility, cleanliness, and freedom from flaking and micro-cracks.—K.E.J.

Ultrasonics cuts grain growth during casting of forging ingot E. B. Wright, D. R. Carnahan, and J. H. Kelley (*Iron Age*, 1959, **184,** Aug. 6d, 84–87) In the vacuum arc casting of metals, large columnar grains tend to grow perpendicular to the solidification interface, resulting in segregation. The experimental use of ultrasonic energy has reduced this effect in the lower part of the ingot. The problems of practical application are considered.—A.G.

Wild-Barfield NRC 600 lb vacuum induction furnace W. Jessop & Sons Ltd. (*Wild-Barfield Heat-Treat. J.*, 1959, **7,** Dec., 10–15) A further account of the installation, its equipment and operation. The pumping and electrical systems are described.

Vacuum furnace for continuous strip (*Met. Prog.*, 1959, **76,** July, 111–113) A pilot furnace operating at up to 2100°F can handle strip up to 4 in. wide and 0·03 in. thick. Metals treated include Ta, Ti, Zr, high-carbon steels, and various stainless steels. The furnace may be heated by electricity or fuel. With clean strip, the pressure can be maintained below 1 micron.

Vacuum arc melting method upgrades low alloy steels (*Steel*, 1959, **145,** Oct. 26, 179, 182) Advantages of the consumable electrode vacuum arc melting process are cited. Some practical applications are described involving the production of high quality ingots and the upgrading of alloys made by conventional means.—A.G.

Standard Steel's vacuum pouring-stream-degassing installation (*Ind. Heat.*, 1959, **26,** Sept., 1754–1756, 1758) A description is given of a process particularly suited for production of low H_2 steel rings for rotating machinery. Advantages are reduction of H_2 content to a low level, reduction of oxide inclusions, O_2 and N_2 contents, and susceptibility to ageing effects. Heat treatment costs are less and ductility and physical properties are improved.

Behaviour of nitrogen in the melting of iron-base alloys in vacuum arc [and induction] furnaces D. A. Shabanov (*Izvest. VUZ Chern. Met.*, 1958, Nov., 37–40) Increases and decreases of N_2 content were observed depending on residual pressure in the furnace and the content of the original metals.

Bubbling helium helps degas steel (*Steel*, 1959, **145,** Aug. 17, 106, 110) In the degassing process described molten alloy steels are held under high vacuum while He is introduced below the surface. H_2 content is said to be reduced from 3·9 to 1·5 ppm in about 12 min.

Gases in iron-vacuum-degassing tests S. Gallo and G. D'Allessandro (*Fond. Ital.*, 1959, **8,** Nov., 397–405) In the light of developments in the vacuum melting and degassing of steels the possibility of applying the technique to iron is examined. The effects of degassing grey and malleable iron are examined. In grey iron, O_2 encourages the formation of shrinkage cavities whereas H_2 and N_2 by stabilizing the carbides eliminate hard points and corners. Degassing of malleable iron accelerates substantially the decomposition of the cementite which begins at a lower temperature and is completed more rapidly. For all types of iron, degassing completely eliminates defects such as microporosity and blow-holes.

REHEATING FURNACES AND SOAKING PITS

The new soaking-pit shop of the Division Montignies de la Société Métallurgique Hainault-Sambre, at Cuoillet (Belgium) E. Maheux (*Acier-Stahl-Steel*, 1959, **24,** (7–8), 335–339) Structural details of the building and pits are given.

No smoke, better heat (*Esso Oilways*, 1959, **10,** (3), 11) The change-over from solid fuel to oil for a forge at Cookley, Worcestershire is mentioned.

Performance of alloy rolls as continuous hearth in alloy slab heating furnace Westinghouse Metals (*Indust. Heat.*, 1959, **26,** Oct., 2028–2029) The rolls are made of centrifugally cast 22H (very high nickel) of 10 in. dia.; they have withstood temp. of 2150°F for three years without replacement.—K.E.J.

Automatic temperature control advantageous in forging furnace operation Finkl & Sons, (Chicago) (*Ind. Heat.*, 1959, **26,** Dec., 2502–2504) A control system, based on three Pt/Pt–Rh couples and a Speedomax recorder in each furnace, is used on a battery of ten regenerative forge furnaces. This has improved quality of the product, increased hearth life, reduced fuel consumption and simplified operation.

Automatic temperature control for slab furnaces Steel, Peech & Tozer Ltd (*Iron Steel*, 1959, **32,** Nov., 537–540) The design, operation, and automatic control system of two pusher-type furnaces installed to serve the new hot strip mill at Rotherham are described.

Design and operation of mill furnaces: Mill furnace practice at the Appleby-Frodingham steel works (*BISRA 3rd plant engineering conference*, 1949, Leamington Spa, March, pp.55) N. H. Turner (5–15). **Mill furnace practice at Clydebridge steel works** W. B. Wright (16–19, discussion 20–26). **Some fundamental aspects of mill furnace design** S. J. Sarjant and C. Hulse (27–41). **The instrument requirements of mill furnaces** F. A. Gray (42–47, general discussion 48–55).

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

The heat-treatment of steel R. Schamschula (*Maschinenwelt Elektr.*, 1960, **15,** March, 85–91) An introduction to the mechanisms, particularly structure transformations, involved in the heat-treatment of steel.—T.G.

Electric resistance furnaces and their applications R. O'Donoghue (*BEAMA J.*, 1959, **66,** Nov., 134–137) A general illustrated review of furnaces and their uses.

Flow patterns in three-dimensional shapes: a background for furnace design N. P. Bacon, J. H. Chesters, and I. M. D. Halliday (*JISI*, 1960, **195,** July, 286–292) [This issue].

Industrial heating equipment highlights R. E. Fleming (*Ind. Heat.*, 1960, **27,** Jan., 25–30) Details are given of American orders for fuel-fired, electric, and induction heating equipment during 1959, with particular emphasis on overseas markets.—K.E.J.

On the heat treatment of the dispersed system magnet alloys M. Chubachi and A. Higuchi (*Sumi. Met.*, 1959, **11,** July, 192–199) Data are reviewed for alloys in the Fe–Ni–Al and Fe–Ni–Al–Co systems, and heat-treatment such as magnetic field cooling, isothermal magnetic field annealing, and two-step tempering. Permanent magnetism is defined in the sub-microscopic state, and is related to the two b.c.c. and one f.c.c. phases, and the nucleation and growth of ppts (13 refs).—K.E.J.

Versatility of new heat treating plant in accord with expanding southern industry (*Ind. Heat.*, 1959, **26,** Nov., 2397–2406) Details are given of furnaces installed at Industrial Metal Treating Co. for basic heat treatment, special tempering, induction hardening, hardening special steels, carburizing, carbonitriding, bright heat treatment, treatment of non-ferrous metals, and vacuum heat-treatment of Ta or Ti.

Industrial electric resistance furnaces in Czechoslovakia V. Roztočil (*Czech. Heavy Ind.*, 1960, (2), 30–37) A survey is given of the types of electric resistance furnaces which are manufactured in Czechoslovakia, most of the furnaces are for the heat-treatment of metals, but other types are also described. Generators for protective atmospheres and switch gear are included in this review.—T.G.

A recuperative furnace for use up to 2000°C E. A. K. Patrick and R. D. Hastie (*Gas Times*, 1959, **93,** Dec., 41–42) A gas-heated furnace with MgO insulation is mentioned, discussion is reported.

On-the-line applications of silicon carbide heating elements E. Macer (*Ind. Heat.*, 1959, **26,** Nov., 2250–2258) Design data are given for Globar elements for use up to 2000°F or above. Curves show the steady increase in resistance with life at various temp., and specific loading data for various atm. Applications in the metal

treatment, ceramic, and chemical fields are described.—K.E.J.

Accuracy and reproducibility in selecting the right temperature control system R. S. Day (*Met. Treating*, 1960, **11**, Jan.–Feb., 4–7, 48) Heat treating is discussed not from the point of view of the instrument maker but from that of product uniformity. Factors in measurement and the securing of accuracy and reproducibility within the limits required by the heat treater are considered.

Accident prevention in relation to annealing and melting furnaces H. Zepernick (*Metall.*, 1959, **13**, Sept., 850–854) Examples from practice are discussed.

On the hardness change when the precipitation hardening process is interrupted Y. Mishima and Y. Kurihara (*Ann. Rep. Eng. Res. Inst. Tokyo*, 1959, **18**, Sept., 181–186) A graph of the change in a Fe–Mo alloy at 40°C after interrupted precipitation hardening is given.—S.H.–S.

Hardening stainless spring steels T. Akutagawa, Y. Mishima, T. Fujita, Y. Yabuki, Y. Sakaba, and K. Inoue (*Ann. Rep. Eng. Res. Inst. Tokyo*, 1959, **18**, Sept., 68–74) A summary of five kinds of precipitation hardening, using Cu, Al, and Ti.—S.H.–S.

Large chromalloy jet engine components hardened by CO_2 quench in bell-type furnace operation (*Indust. Heat.*, 1959, **26**, Oct., 1958–1962) A furnace at General Electric Corp. hardens cylindrical components up to 4 ft. dia. and 4 ft high with the min. of distortion. They are heated for hardening to 1725°F in a protective atm., soaked for 1 h and then quenched to 1000°F within 3 min. by vaporized CO_2. The tempering and cooling cycles are described.—K.E.J.

Cast high alloy continuous belt and radiant tubes form heart of new continuous atmosphere furnaces E. A. Schoefer (*Indust. Heat.*, 1959, **26**, Oct., 2017–2024) Continuous belts and radiant tubes in furnaces made by surface Combustion Corp. allow high-temp. carburizing or clean hardening, followed by quenching and tempering, to be done on small parts at rates of up to 1500 lb/h. The belts and tubes are made in heat-resistant HT cast alloy (35%Ni, 15%Cr).—K.E.J.

The shaker hearth furnace W. F. S. Taylor (*Met. Treatment*, 1959, **26**, Dec., 437–440) A 40 kW shaker hearth furnace used for the continuous hardening of bolts in an exothermic atmosphere at Lindley & Co., Halifax, is described. The bolts are tempered in a gas-fired furnace. Running costs are considered.

Heat treating the stainless steels. IV S. W. Cole (*Ind. Heat.*, 1959, **26**, Nov., 2230–2240) Hardening data are given for the martensitic stainless steels. They include a chart showing hardness ranges for specified steels after hardening, stress relieving, tempering, and annealing; and information on the effects of carbon and chromium and hardening temp. on hardness, and of initial hardening temp. on mechanical properties.

Recent installation of gaseous carburising furnaces (*Mét. Const. Méch.*, 1959, **91**, Dec., 925–935) American and French techniques are compared. Examples of particularly remarkable plants are cited including continuous furnaces at the Régie Renault and carburizing times at the new Simca works.—S.H.–S.

The depth of case-hardening obtainable in induction hardening at a frequency of 10 kc/s G. Seulen and H. Geisel (*Forsch. Wirts. Nordrhein–Westfalen*, No.747, 1959, pp.25) The required depth of case-hardening can be obtained in induction hardening by selection of the correct parameters. For a frequency of 10 kc/s and a constant inductor width of $\frac{1}{2}$ in. diagrams are presented which assist the selection of these parameters. The experiments and their results are described in detail.—T.G.

Gas carburisation of rolling mill gears G. C. Simpson (*Anvil*, 1959, **5**, Christmas, 4–7) The evolution of the closed furnace technique and its operation at Darnall is illustrated.

Unique two-stage case hardening improves product, reduces warpage R. Buyea (*Ind. Heat.*, 1959, **26**, Dec., 2458–2462) For critical automobile parts requiring case-hardening up to 0·030 in. with no warpage, Allcase enclosed quenched type furnaces are used. For example, stamped parts are carburized at 1600°F for 3½ h., and then the temp. is equalized at 1385°F before oil-quenching. This gives a uniform, modified carbonitrided case with little retained austenite.—K.E.J.

High quality truck parts uniformly produced in new carburising installation (*Ind. Heat.*, 1959, **26**, July, 1324–1326) The furnace has precise control of dew-point and temp. through five different zones, and gives a uniform high quality of case depth and hardness. It automatically carburizes 700 lb of parts per h at the White Motor Co. Works. The cycle is 19 h, case depth 0·065 in., and final hardness RC59–63.—K.E.J.

Oxy-acetylene flame hardens gears and dogs D. J. Fishlock (*Metalw. Prodn.*, 1960, **104**, March 2, 389–392) An account of Vauxhall Motors plant at Dunstable. The storage and piping system for the C_2H_2 is described and the Gleason hardening machines and other equipment are referred to.

Novel form of heat treatment reduces foundry rejects (*Iron Age*, 1959, **184**, Sept. 17, 116–118) The technique described, termed determinant tempering, involves the isothermal annealing of castings during solidification at a temperature corresponding to the nose of the T–T–T curve. This is claimed to cut rejects and to improve the quality of alloy steel castings.

Heat treating the 'caterpillar' track J. L. Brown (*Ind. Heat.*, 1959, **26**, Dec., 2436–2440) Details are given of the heat-treatment and assembly methods used for the track shoes and their various auxiliary parts, all made of SAE carbon steels. Points of interest are selective tempering of the shoe by induction heating so that the cleat retains max. hardness, and the uses of 'Neutralene' protective atm. to prevent oxidation or decarburization.

Spring steel strip: Data sheet no.26 (*Eng. Mat. Design*, 1959, **2**, Dec., 633) Tables of mechanical properties and tempering charts are given.

500,000 psi Steel Ford leaps the tensile barrier Ford Motor Co. (*Steel*, 1959, **145**, Sept. 21, 84–86) By the Ausforming process, which involves heavy mechanical working in the 800 to 1050°F range followed by transforming to martensite and tempering, steels have been produced with tensile strengths above 400000 psi. These strengths accompanied by good ductility are attributed to the very fine grained martensitic structure.—A.G.

Heat-treat break through seeks 1 million psi strength: upgrades low-alloy characteristics L. Kuzela (*Western Metalw.*, 1959, **17**, Nov., 35–36) A special heat-treating method called Thermodmagnadynamics by its discoverer, W. I. Bassett III, of Gardena, Calif., is said to be capable of increasing ductility along with tensile strength 'to infinity'. The process itself is not described, but it is mentioned that time and temp. are altered and that furnaces and equipment require special modifications.—T.G.

Causes and prevention of surface fissures on hot-worked steel products. IV. Influence of sulphur in heating atmosphere and 'sulphide treatment' on surface fissures T. Ohtake, K. Ishizaki, and N. Eguchi (*Nippon Kinzoku*, 1959, **23**, Jan., 15–19) Surface fissures in steel can be prevented by scattering fused FeS or FeO–Na_2S mixture on the surface (mechanically freed from scale), leaving till molten, and then hot-working or by immersion in molten FeS before hot-working. This is explained by reaction with non-ferrous metals. When steels are heated in atm. containing sulphur, the depth of cracks decreases with increase of SO_2, but penetration of a ternary eutectic scale increases.—K.E.J.

FORGING, STAMPING, DRAWING AND PRESSING

Forging of metals R. Roy (*TISCO*, 1959, **6**, Oct., 234–247) Methods of forging, selection of stock, choice of equipment, testing and inspection of forgings are considered.

Steels for forging R. J. Brown (*JISI*, 1960, **195**, July, 278–286) [This issue].

Forging and the space age J. H. Jackson and H. B. Goodwin (*Met. Prog.*, 1959, **76**, July, 65–71) To maintain its position, the forging industry needs more research into the fundamentals of flow of metals, the working of high-tensile materials, increased precision and mechanization. Such work is typified by a programme on fundamentals of press forging and extrusion for Air Force requirements, which is described.—K.E.J.

The intermediate stages in die forging and their production by roll forging K. Spies (*Forschungsber. Land Nordrhein–Westfalen*, 1959, (728), pp.113) The theory and practice of the production of the intermediate stages of die forgings by roll forging as opposed to drop forging are described and the advantages offered by this type of working stressed. A number of examples are quoted and illustrated. The economics of the process are also mentioned (43 refs).—T.G.

The new fabricating plants for the manufacture of large forgings in the Gerlafingen works G. Ehrensperger (*Roll'achen Werkzeit.*, 1959, **30**, Sept., 110–115) The forging press, machining, and inspection procedures in the new plant at Gerlafingen are described.

Forging effects on the mechanical properties of three boron-treated steels E. Di Cesare (*WAL–TR*–312/80, *PB* 151814; 1959, July, pp.48 from *Nucl. Sci. Abs.*, 1959, **13**, Oct. 31, 2434) Steel alloys 14B35, 14B50, 10R70 containing B and rare earths were hot-forged by upsetting and drawing out. Longitudinal and transverse tensile and Charpy specimens and micro- and macro-specimens were tested and examined in the as-forged and in the heat-treated conditions. Heat treatment resulted in optimum tensile properties and toughness at 66% reduction for the swaged ingots, 50% for the upset-forged 14B35 alloy, and 0% for the upset forged 14B50 and 10R70 alloys.

Hydrogen in heavy forgings J. E. Steiner (*Met. Prog.*, 1959, **76**, July, 72–75) The major problems of flaking and low tensile ductility in heavy forgings are best solved by lowering the H_2 content. The lowest limit with careful melting practice appears to be 2·0±0·8 ppm, but vacuum melting of ingots up to 110 in. in dia can give a uniform 1 ppm on forgings.

Materials handling in American drop forging W. G. Kirkwood (*ESC News*, 1959, **13**, Summer and Autumn, 6–11) Observations during a visit to the US are reported. Storage, billet transfer, handling through heating, forging, movement to stamp or press, heat-treatment, descaling, and finishing are briefly discussed.

Line rolls precision rings from low-cost billets (*Iron Age*, 1959, **184**, Aug. 27, 79–81) An account is given of a fully automated line which hot forges and roll-forms bearing races and other precision metal rings from inexpensive billet blanks.—A.G.

The forging of Admiralty type anchors M. Maruszak and Z. Werens (*Hutnik*, 1959, **26**, (11), 453–457) The authors describe in detail the operation involved in forging a solid anchor of 1500 kg and point out the high cost and impracticability of this technique. It is necessary to examine the delivery conditions and to admit the use of cast anchors. Attempts should be made to manufacture anchors from cast iron in the normalized state or even from improved scrap.

Metal flow in forging. XII. Calculation of back pressure in a steel ball rolling machine T. Awano and M. Ochiai (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1959, **8**, Oct., 686–695) A method for the calculation of the back pressure in ball rolling is suggested and the results are compared with the back pressure measured with the experimental steel-ball rolling-machine described previously. Agreement between theory and experiment is fairly good. **XIII. Ball rolling die designed from the stand-point of back pressure** (Nov., 768–774) The back pressure is affected by the dimensions of the ball rolling die, viz. the inlet part and the forming part. The rolling back pressure is kept low if the forming part is kept short.—T.G.

Drop stamping parts for jet aircraft noise suppressors Douglas Aircraft Co. Inc (*Machinery*, 1960, **96**, Jan. 20, 127–128) Stainless steel shaping and fabrication is noted.

Manufacture of wheels and tyres M. S. Gopalan (*TISCO*, 1959, **6**, Oct., 248–259) Railway equipment is reviewed.

Hot dies aid forging Armour Research Foundation (*Steel*, 1959, **145**, Oct. 5, 92–93) A technique of forging with heated dies is described which shortens forging sequences and

reduces final machining. The die is assembled from four cast layers of Inconel 713C and heat from Calrod units maintains a temperature of 1600°F.—A.G.

The production of cable chains: New plant installed by Brown, Lenox & Co. Ltd (*Weld. Met. Fabr.*, 1960, **28,** Jan., 2–8) The new plant for the production of high-tensile chains is described. The plant layout allows a continuous forward work flow. The end of the links are joined by automatic flash welding. The process of chain making is described in detail including the heat-treatment and testing.—T.G.

How to identify a good hot work die R. F. Harvey (*Steel*, 1959, **145,** Oct. 19, 150–151) A series of photomicrographs of AISI type H–12 hot work die steel is presented. These show typical good and bad microstructures in the annealed and heat treated material.—A.G.

This die was made in 15 hours. Standard methods take 250 A. E. Payne (*Steel*, 1959, **145,** Oct. 19, 158–169) In the die-making process described the required outline is scribed on a prepared die blank and the bulk of the metal is removed by drilling. Broaching in a 2000-t hydraulic press follows and excess metal is flattened into the base cavity. Advantages claimed are low initial and maintenance costs and the use of regular tool steel.—A.G.

Automatic die lubrication improves forging quality (*Steel*, 1959, **149,** Sept. 7, 101) By spraying colloidal graphite on to forging dies after every strike, better forgings and longer die life are said to be achieved. Automatic equipment to effect this spraying is described.

Special metal-working techniques B. R. Nijhawan (*TISCO*, 1959, **6,** Oct., 290–298) Advances in the rolling of metals, extrusion, wire drawing, and explosive forming are considered.

Production of inductor caps from non-magnetisable steel H. Fiedler and G. Richter (*Neue Hütte*, 1960, **5,** Jan., 21–31) The stressing of inductor caps in practice and the steels used in their manufacture are described, and the production of these forgings at the VEB Gröditz works is discussed. Trials to investigate the influence of hot and cold working and heat treatment on mechanical and electrical properties are reported.

Utilization of steel swarf: Russian forge-welding process P. G. Morgan (*Iron Coal Trades Rev.*, 1960, **180,** Jan. 29, 253–254) A process not requiring large presses is outlined.

The cold working of steel (*Auto. Eng.*, 1959, **49,** Dec., 528–530) The use of phosphate coatings as lubricant is described.

Strengthening the undercut of shafts I. V. Kudryavtsev and N. A. Balabanov (*Vestnik Mashin*, 1960, (1), 28–31) Various types of steels and of high strength cast iron in specimens of a given size in the form of a stepped shaft were hammered by means of a special machine consisting of a rotating cam actuating a spring-loaded hammer which could deliver up to 2000 impulses per min, in its reciprocal motion. The increases in strength obtained as a result of these tests are tabulated for the different materials tested.

Complex forms shaped with highly formable stainless (*Western Metalw.*, 1959, **17,** Nov., 51) The fabrication of more than 100 ft of stainless steel tubing employed in jet-type aircraft anti-icing systems is possible because of the inherent qualities of the AM–350 stainless steel of which the tubing is made. The tubing of an anti-icing system must withstand about 700°F.

Progress in metal forming D. V. Wilson (*Met. Prog.*, 1960, **77,** Jan., 71–76) Forming practices in Europe and USA are reviewed; it is pointed out that recent advances have been due more to the engineer than to the metallurgist, and that metallurgical improvements are possible in several fields, including the development of new cold drawing alloys and methods of pressing.

Investigations into the wear of punches and dies W. Crasemann (*Machinery*, 1959, **95,** Dec. 23, 1326–1328) Work at Hanover is summarized. The process of shearing of sheet materials is considered and measurements of wear and burr formation are described. Mn and Cr tool steels are compared.

Buckling limits of tool dimensions in cupping operation M. Miyagawa (*Mem. Fac. Techn. Tokyo Univ.*, 1959, (9), 617–630) [In English] An analytical treatment, based on previous theoretical formulae for the mechanisms of wrinkling and puckering, enables buckling limits to be determined for drawing tools. These give design data for the dia. and contour of the die, contour of the punch, and die-punch clearance for particular thicknesses and dia. of blanks in various cupping operations (23 refs).

Explosive forming in Canada H. P. Tardif (*Met. Prog.*, 1960, **77,** Jan., 128–130) A general review of research work being carried out in Canada on techniques and properties of the work produced.

Forming sheet metal with explosives Ryan Aeronautical Co. (*Machinery*, 1959, **95,** Dec. 16, 1287–1290) The forming of parts, including stainless steel parts by explosions while immersed in water at the plant in San Diego, Calif. is described and illustrated.

High energy rate metal forming G. N. Bardin A. H. Petersen, G. W. Papen, and E. H. Spaulding (*LR* 13627; *PB* 151849, 1959, March pp.66) Tests over a three-months period are described on explosive forming methods and the elongation, thinning and quality of the products are determined as part of an effort to select the optimum method.

Production of stepped hollow shafts by liquid bulging. III. Lubricants and frictional forces T. Ogura, T. Ueda, and M. Ishikawa (*Rep. Gov. Ind. Res. Inst., Nagoya*, 1959, **8,** Sept., 603–608) The frictional forces between a steel pipe and the cylindrical die in the hydraulic forming of hollow stepped shafts were measured as a function of the lubricant applied. It was found that Molycote-G was superior to all other lubricants, particularly in connexion with bonderizing.—T.G.

Shift to pretempered steel slashes costs 57 per cent (*Steel*, 1959, **145,** Aug. 24, 92) By the use of pretempered coil steel, computer parts are now fabricated without heat treatment, tempering, or reworking. Parts are formed by a series of carbide dies.—A.G.

Apparatus for the measurement of drawing forces J. Jońca and J. Rabalski (*Prace Inst. Hutn.*, 1959, **11,** (5), 261–266) A prototype apparatus was designed and built. A hollow, elastic, steel toroid was used as the transducer. Strain gauges attached to the inner and outer surfaces of the toroid were connected to a resistance bridge circuit. An accuracy of $\pm 2\%$ was obtained which is satisfactory for experimental and production use. It was found that the apparatus was simple to construct and service and was reliable under production conditions.

Cold drawing: Swaging high-strength heat-resistant alloys Boeing Airplane Co (*Aircraft Prod.*, 1960, **22,** Jan., 37) A note on an eight-stage tube reduction process.

Effect of heat-treatment prior to drawing on reduction per pass and on the optimum magnitude of the back tension (Hardness distribution in steel wires). II T. Nishioka and Y. Yasukuni (*Nippon Kinzoku*, 1959, **23,** Feb., 90–93) [Summary in German] An apparatus is illustrated, which is in fact a modified tensile testing machine, for determining the drawing forces required in drawing wire with and without back tension. The distribution of the hardness across the section of the wire is given in diagrams and it can be seen that back tension results in a more even hardness distribution across the section. The larger the drawing angle, the less is the effect of back tension.—T.G.

Wire drawing V. Prakash (*TISCO*, 1959, **6,** Oct., 215–223) The present methods of wire drawing are reviewed, and the theories of Lewis, Sachs, Siebel, and Hill and Tupper are considered.

Notable expansion at Dorman Long's Cleveland Wire Mill (*Wire Ind.*, 1959, **26,** Dec., 1188–1192) Recent innovations and new plant at the Cleveland Wire Mill, including those for preparing wire cables for the Forth Road Bridge, are described. One man in the cleaning house handles 500 t of work per week.—D.L.C.P.

Construction and efficient design of wire twisting plant H. W. Aengeneyndt (*Wire*, 1960, Feb., 14–21) Types of steel for producing twisted concrete reinforcing wire are described, and their manufacture and properties discussed.

Extrusion of metals S. S. Bhatnagar and P. K. Gupte (*TISCO*, 1959, **6,** Oct., 224–233) Various methods of extrusion are described. The advantages and drawbacks of extrusion are discussed, and the extrusion properties of many metals and alloys are given.

On the Ugine-Sejournet process K. Morikawa and H. Kojima (*Sumi. Met.*, 1959, **11,** July, 215–223) A review dealing with various installations in different countries, the technical aspects of the process, and the range of sections that can be produced.—K.E.J.

Hydraulic horizontal extrusion and tube processes W. Dohrn and H. Stapel (*Z. Metallk.*, 1960, **51,** Feb., 65–72) The authors present an account of the characteristics and advantages of the hydraulic horizontal extrusion and tube press and its auxiliary equipment. The presses discussed here are the well-known Schloemann presses. The metals extruded in these presses range from light metals to steel.—T.G.

ROLLING MILL PRACTICE

Rolling of metals S. Visvanathan (*TISCO*, 1959, **6,** Oct., 201–214) A review of rolling theory.

Research on the rolling process I. P. Bardin (Ed.) (*from *Metallurgiya USSR*, 1917–1957: *Metallurgizdat*, 1959, (2), 56–81) A chapter of the book is given with the historical survey and review of theories of rolling pressure and deformation (252 refs).

On the deformation process in cold-rolling S. Muromachi and S. Hori (*Nippon Kinzoku*, 1959, **23,** Jan., 11–14) Studies with a network specimen (square copper) show that during rolling, deformation begins earlier in the centre of the bar with low reductions (1·5 and 4·1%) but in the outside layers with high (8·2 and 28·5)%. After rolling, the magnitude of rolling reduction and no. of repeated passes have little effect on the pattern of strains in the vertical section except in a thin surface layer (11 refs).—K.E.J.

An appraisal of rectifier circuits for reversing mills and their automation O. Martin and H. Bösel (*Stahl Eisen*, 1960, **80,** Feb. 18, 207–210) The merits of half-wave and full-wave rectifiers are discussed and their fields of useful application outlined. The limits of automation in the programming of rolling mills are briefly mentioned.—T.G.

Sheet metal grader Bren Manufacturing Co. (*Mech. Hand.*, 1960, **47,** March, 167–168) Sheets are accepted or rejected for thickness on a tolerance of $\pm 0{\cdot}0005$ in., or for perforations or surface condition. The stack heights are photo-cell controlled.

Digital servo-mechanism for controlling the screw-down mechanism of a reversible rolling mill V. M. Ozernoi and G. S. Rozenberg (*Avtomatik i Telemek*, 1959, (11), 1528–1536) Schematic diagrams are given of a scheme for a servo-mechanism which can control not only the screw-down of a reversible hot-rolling mill but also mechanisms which can be program controlled. Formulae are given for the main logical units and also circuits for certain blocks.

Granite City doubles horsepower of tandem cold mill A. W. Schlechte, R. G. Nolan, R. M. Peeples, and D. E. Rea (*Iron Steel Eng.*, 1959, **36,** Dec., 117–126) Details of this modification, carried out by Granite City Steel, are given. Techniques employed included oxygen powder lancing of concrete foundations which minimized the need for blasting, use of prefabricated beam construction and false ceiling, and a computer board study. Installation of a new busbar before shutdown saved a great deal of mill downtime.

62000 miles per year (*Esso Oilways*, 1959, **10,** (3), 5–6) Output from the Belgian Ferblatil cold-rolling mills is described.

Electricity in the steel industry: VIII. Mill drives for cold rolling P. E. Peck (*Elect. J.*, 1959, **163,** Nov. 13, 1008–1012, 1015) Drives and control mechanisms are reviewed.

Continuous thickness measurement during rolling by means of radiation H. Hart (*Z. Metallk.*, 1960, **51,** Feb., 120–131) An illustrated review of current practice and equipment used for the continuous thickness measurement in rolling mills by β- and γ-radiation.—T.G.

Form and cut parts continuously Armour Research Foundation (*Iron Age*, 1959, **184,**

Dec. 24, 51) A new cut-off and forming machine developed by the Armour Research Foundation is described. The invention is a continuous chipless process for rolling wire or bar stock to shape; operations include thread forming, upsetting, and cut-off. The device includes a form roll with constant root diameter and helical forming roll of increasing height. Rotation of the form and back-up rolls rotates the stock, which is drawn axially along the rolls, while the helical form shapes the part. Operation is continuous and there is no waste material.—D.L.C.P.

Some unusual defects on cold reduced flat products J. Le Bas (*BHP Tech. Bull.*, 1959, **3,** Sept., 30–37) A report on investigational work on some defects in the output of Flat Products Division of the Broken Hill Pty. Co. Ltd, at Port Kembla.—S.H.–S.

Automatic shear lines McKay Machine Co. (*Auto Eng.*, 1959, **49,** Dec., 526–527) Presses and shear lines handling coiled stock up to 72 in. wide is reviewed.

Control of stocks by simple rules R. H. Collcutt (*Engineering*, 1960, **189,** Feb. 12, 232) A note from BISRA on the optimum level of a steel rod stock.

Calculating weights of steel bars: some ready methods H. Jackson (*Iron Steel*, 1959, **32,** Oct., 492–493) Formulas and examples are given of the calculation of weights of bars of various sections. The calculations are intended to simplify the work of the issuing clerk in a steel store or warehouse.

MACHINERY AND SERVICES FOR IRON AND STEEL PLANT

Electronic weighing machines for use in iron and steel works H. Knüppel and G. Wiethoff (*Stahl Eisen*, 1960, **80,** Feb. 18, 220–233) The principles and applications of various types of electronic weighing machines built into the cranes of iron and steel works are described and a number of examples quoted. The favourable effect of weighing on the proper control of the flow of the materials in the iron and steel industry is stressed.—T.G.

Steel works electrification (*Iron Steel Rev.*, 1959, **3,** Sept., 49) The arrangements to meet 28 mW maximum demand at the John Lysaght's Scunthorpe Works are described.

Durgapur power station B. K. R. Prasad (*Elect. Times*, 1959, **136,** Nov. 5, 499–500) Plans for the new station are discussed.

WELDING AND FLAME-CUTTING

The twin-arc welding process W. D. Waller (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 111–115) The advantages of the twin-arc process, particularly the saving in cost and the higher productivity rate, as compared to a single-arc process, are discussed.

The organization of a modern fabrication shop A. G. Thompson (*Weld. Met. Fabr.*, 1960, **28,** Jan., 24–28) The layout and organization of shops for welded fabrication is briefly discussed with special reference to: stockyard, plate preparation, section and bar preparation, stowage and sorting, assembly, erection and heat-treatment, welding, and finally inspection.—T.G.

Welding work on manganese steel G. Neuhofer (*Schweisstechn.*, 1959, **13,** May, 54–56) The difficulties of welding 12%Mn steel—structural transformation on heating, a high coefficient of expansion and low thermal conductivity—are reviewed, and measures to overcome these disadvantages are discussed. A low current and rapid welding, followed by hammering and rapid cooling are recommended. Some examples of the repair welding of this material are given.

Survey of the welding processes H. Nix (*Schweisstechn.*, 1959, **13,** Oct., 109–114) After discussing the various types of jointing such as welding and soldering, the effect of O_2, N_2, and H_2 on welds is explained. The principles of the individual welding processes are then described and illustrated.—T.G.

The principles of the modern arc torch R. M. Gage (*Weld. J.*, 1959, **38,** Oct., 959–962) The principle, design, and operating data of the plasma-jet torch are described. The article concludes with a diagram of an experimental non-transferred arc torch.

Automatic arc and resistance welding as applied to sheet and strip metal J. A. Dorrat (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 116–136) A review of the joints made, electrodes used, and machines available.

Weld AM-350 strip into tubing (*Iron Age*, 1959, **184,** Dec. 31, 44) Properties of high strength stainless steel (AM-350) tubing is described. Welded tube can be drawn and annealed so that the weld area is indistinguishable from the base metal and responds to hardening treatment.—D.L.C.P.

Growth of the CO_2 welding process D. F. Ritchie (*Can. Metalw.*, 1959, **22,** Sept., 16–18, 20) A general account of the process and its advantages and results.

Welding of low-alloy steels H. Thielsch (*Can. Metalw.*, 1959, **22,** Oct., 34–36) A lecture covering procedures, electrode selection, metallurgical problems, and preheat and post heat of weld and heat-affected zone.

Welding and heat-treating rocket cases C. N. Scott (*Met. Prog.*, 1959, **75,** March, 99–102) Rocket engine cases are fabricated from precision weldments of various types of alloy steels such as 4130, 4132, 4135, and 1020, which are heat-treated to give high strength. Cases are quenched from austenitizing temp. into salt at 350°F to minimize distortion.—T.G.

Submerged-arc welding of thin gauge low alloy steel sheet C. A. Terry and A. B. Tinsley (*Weld. Met. Fabr.*, 1959, **27,** Dec., 454–460) Submerged-arc welding technique is described and details given of problems encountered in experimental tests with SAE 4130 sheets 0·092 in. thick, followed by metallurgical investigation and discussion of results.

Design and drawing of electric fusion welded structures O. Grossi (*Ing. Mecc.*, 1959, **8,** Nov., 17–23) In this third article in the series the author describes and illustrates machine components obtained by fusion arc welding. First he discusses the problem of the conversion of the forged or cast elements into composite structures by welding. Then he gives examples of the technique applied indicating the advantages and disadvantages of the method used in each individual case.

Fabricator scores breakthrough in joining titanium clad steel Chicago Bridge & Iron Co. (*Steel*, 1959, **145,** Oct. 19, 152–153) Ti-clad mild steel sheet has been made by a vacuum brazing process. These sheets can be fabricated into corrosion-resistant pressure vessels by a special welding technique involving a silver inlay at the mild steel joint capped with a Ti cover strap.—A.G.

Process welding of nodular and gray-iron castings B. Townshend and E. O. Porter (*Weld. J.*, 1959, **38,** Aug., 329s–334s) Gray cast iron to ASTM A278–33 and nodular cast iron to ASTM A395–56T can be welded satisfactorily using the shielded metal-arc process under certain conditions of electrode type, arc length and preheat temp.; if the surface of the work is 'buttered' with the same electrode and preheat temp., followed by stress relief or anneal, the remainder of the weld can be finished at room temp.

Automatic welding of thin sheets of different steels under flux K. B. Lyubavskii and M. I. Sorokina (*Svar. Proizv.*, 1959, (11), 3–6) The method proposed is based on results of technological investigations, on the selection of suitable fluxes, and on the data from strength tests and structure analysis of the weld metal and welded joint, and is recommended for the butt welding of thin sheets of 30KhGSA and E1654 steels.

Fusion welding precipitation-hardening steels R. Meredith (*Weld. J.*, 1959, **38,** Oct., 963–968) Welding characteristics and physical properties of welded joints of 17–7 pH and 17–4 pH stainless steels are examined, and examples of their fabrication given.

Technological and metallurgical aspects of electro-slag welding E. Bishop (*Weld. Met. Fabr.*, 1959, **27,** Dec., 461–467) A condensed attempt to deal with the basic parameters of the process as used on mild steel in the Soviet Union, and, secondly, with particular problems arising with electro-slag welding of low alloy and stainless steels, with a cursory reference to the welding of Ti.—S.H.–S.

Tungsten-arc welding the root pass of power-pipe joints R. W. Bennett (*Weld. J.*, 1959, **38,** Dec., 1175–1181) This is a combined review and Pipe Fabrication Institute report. Weld joint designs as affected by pipe size, tacking, welding conditions, and welding technique are considered, and a chart (due to Schaeffler) is presented to aid in calculating the effects of composition when welding En58 steels.

Projection welding of mild steel G. A. Phipps (*Weld. J.*, 1958, **5,** Dec., 569–552) A revision of part of publication T30 of the Brit. Welding Assoc. code of practice on sheet welding.

Industrial resistance welding applications R. W. Ayers (*Elect. Rev.*, 1959, **165,** Dec. 4, 775–778) Welding machines are illustrated and uses in motor-cars, wheel welding, aircraft, and constructional engineering are briefly indicated.

The new arc butt welding process for railway rails K. Zwirchmayr (*Schweisstechn.*, 1959, **13,** Oct., 115–117) The rails should have smooth, square ends free from oxide and grease, they are placed in the correct position with a gap 15 mm wide. This gap is filled by arc welding. The economic advantages over the old thermit process are stressed.—T.G.

Recent developments in heavy fabrication practice. II A. D. Barker (*Weld. Met. Fabr.*, 1960, **28,** Jan., 29–37) A description of the individual stages of heavy-plate fabrication involving welding.—T.G.

Solved: welding problem for thin-wall, high strength steel missile tank E. P. Owen (*Western Metalw.*, 1959, **17,** Oct., 52–53) A problem in connexion with an undesirable air tank condition in the Corporal missile, and its solution by an EB insert instead of backing strip are described.—S.H.–S.

The A.B.C. of welding 'T-I' steel U.S. Steel Corp. (*Steel*, 1959, **145,** Sept. 14, 164–165) Recommended methods for welding T-I low-alloy steel are given. The importance of correct welding procedure, dry low-H_2 electrodes and the avoidance of overheating are stressed.

Welded clad steel pipe for reactor construction W. H. Funk (*Weld. J.*, 1959, **38,** Aug., 766–771) New welding procedures for ensuring strength and corrosion resistance of welded stainless-clad steel pipe tested at Lukens Steel Co. are described. In fabricating lengths of clad pipe in a closed system with the stainless steel on the interior, C-steel is deposited on stainless steel without embrittlement.

Welded columns for a steel structure A. S. May (*NZ Eng.*, 1958, **13,** Feb. 15, 78–80) The fabrication of columns for a seven-storey building is described.

Rolling and welding type 430M tubes to stainless steel overlaid carbon steel tube-sheets R. W. Bennett, R. P. Meister, and R. J. Kerton (*APAE–Memo*–175, 1959, Feb., pp.60; from *Nucl. Sci. Abs.*, 1959, **13,** June 15, 1346) The techniques are worked out.

Welding of fuels and controls for Dresden nuclear power station C. N. Spalaris and J. W. Weyers (*Weld. J.*, 1959, **38,** Aug., 760–765) Ferrous applications discussed in this article include the fabrication of B-containing stainless steel control rods. This requires special weld-junction geometries and techniques to overcome brittleness and distortion (5 refs).

New method of welding stainless steel trim J. A. Edwards (*Product Fin.*, 1959, **12,** Sept., 79) A process reducing eleven former separate operations to three and giving a stronger product without having weld marks on pieces is very briefly described.—S.H.–S.

Pre-heat and post-heat treatment in ferrous welding I. G. Hamilton (*J. Metallurg. Club*, 1958–59, (11), 45–52) The effects of microstructural changes, the establishment of preheat temperature, the effect of residual stresses, and the establishment of stress relieving conditions are statistically reviewed.

Semi-mechanical welding under CO_2 as protective gas in the manufacture of chemical containers and apparatus R. Faulstich (*Schweissen Schneiden*, 1959, **11,** Aug., 319–322) Practical directions for the satisfactory CO_2 welding of this equipment are given, with some examples.

Submerged-arc welding of low-alloy steel sheet. II. Development of production welding techniques C. A. Terry and A. B. Tinsley (*Weld. Met. Fabr.*, 1960, **28,** Jan., 9–15)

Methods of overcoming the difficulties in the manufacture of thin-walled tubes from low-alloy steel sheet by the submerged-arc welding process are described and discussed, with particular reference to the use of flux backing techniques.—T.G.

The Russian process of automatic welding under fused flux J. Sebille (*Rev. Soud.*, 1959, **15**, (4), 175–198) Based on information obtained on a visit to Eastern Germany, the author reviews in considerable detail the development of electroslag welding, technical and economic aspects of the method, and its metallurgy and range of applications.

Dip-transfer carbon dioxide welding R. W. Tuthill (*Weld. J.*, 1959, **38**, Oct., 976–981) The dynamic characteristics of the power supply and its effect in manual low-current CO_2 gas-shielded consumable-electrode welding are discussed, and the advantages of the process are described with examples.

Possibility of welding stainless steel and Zircaloy 2 A. Bassi, E. Brutto, C. Corsetti, and G. Peroux (*Met. Ital.*, 1959, **51**, Nov., 509–514) In the erection of nuclear power plant the jointing of steel and Zircaloy pipes presents a considerable problem. After describing the difficulties of jointing and possible methods of welding the two types of alloy the writers discuss preliminary results of researches now being carried out at the Laboratorio di Tecnologie of CISE di Milano.

Manufacture of Fretz-Moon tubes J. Thomson (*TISCO*, 1959, Oct., 299–310) A description of the process of producing welded seam tubes on the Jamshedpur mill.

Getting rid of moisture in electrodes H. Thomasson (*Canad. Metalw.*, 1959, **22**, Nov., 36–37) Practical measures for eliminating moisture in welding electrodes are described; this is often necessary to prevent porosity and underbead cracking. Main recommendation is the use of a portable oven for drying electrodes before use.—D.L.C.P.

Welding and steel structures A. J. P. Tucker (*Eng. Found.*, 1959, **25**, Aug., 68–76, discussion 76–78) Joint design for steel constructions is considered at length with a note on the plastic theory of structures.

The influence of 'Joint Design' on 'Solderability' G. L. J. Bailey (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6**, 149–159) The effect of angle of contact on 'solderability', and the influence of joint design on the flow of solder are discussed.

Metallurgical considerations in the welding of stainless and high-temperature steels A. Bernstein (*Schweissen Schneiden*, 1960, **12**, Feb., 55–61) The author discusses the relation between parent metal and filler metal in the welding of stainless and high-temp. steels on the basis of recent publications.—T.G.

Metallographic studies of weldments in plain and low-alloy steels W. Marfels (*Schweissen Schneiden*, 1960, **12**, Feb., 61–68) This is a general review on the metallography of weldments of plain and low-alloy structural steels, the facts which are revealed by macro- and micro-structures, the effect of the heat-affected zones and the use of TTT diagrams which afford an insight into austenite transformations.—T.G.

Non-destructive weld tests G. Moravia (*Costruzione Met.*, 1959, **11**, Nov.–Dec., 14–25) After a description of some preliminary tests which are carried out on the basic metal and on welded samples before welding, the physical principles are given on which non-destructive tests in current use are based. The main weld defects are listed together with their causes and the extent to which the methods used can detect them. Finally the interpretation of results and the best methods of test programming are described.

Methods for assessing long-term strength of welded joints A. V. Stanyukovich and V. N. Zemzin (*Zavods. Lab.*, 1959, (6), 715–721) Transversal and longitudinal welding joints are investigated under load for long-term strength in different types of steel. The longitudinal investigation of welding joints, which has not been usual up to now reveals the conditions relating to the simultaneous behaviour of the separate zones of the welded joints.

Study of the mechanical properties of an electroslag weld W. Soete (*Rev. Soud.*, 1959, **15**, (4), 199–203) The results are given of tests on electroslag welds of the size, direction, and distribution of the principal stresses on the weld surface and of the weld-affected zone; impact strength of the metal deposited, the base metal and the transition zone, and the fatigue strength of the assembly.

Control of process variables—key to the successful welding of foil J. Campbell (*Weld. J.*, 1959, **38**, Dec., 1183–1191) Butt welding of 18/8 stainless foil of thickness 0·005, 0·003, and 0·002 in. was investigated. The success of the operation was found to be dependent on edge preparation, arc current and voltage, arc length, speed of travel, addition of filler metal in a suitable form, electrode composition and shape, and the design of the weld backing. Results of tensile tests on welds made under various conditions are given.

Peculiarities of the austenite transformation in welding by fusion M. Kh. Shorshorov, B. A. Smirnov, and V. V. Belov (*Svarochnoe Proizv.*, 1960, (11), 12–15) It has been shown experimentally that heating in the range Ac_1–Ac_3 and the time the heat affected zone is above Ac_3 greatly affects the homogenization of the austenite and the grain growth. The austenite transformation during welding may show two tendencies (a) in steels with a limiting content of carbide-forming elements the high temp. of the heat-affected zone favours grain growth and increases the resistance of austenite, and (b) in steels with carbide-forming elements rapid heating with a short time in which the metal is above Ac_3, the homogenization is reduced and also the resistance of the austenite.

Effect of arsenic on weldability and notch toughness of mild steel British Welding Research Assoc. and Stewarts & Lloyds (*Weld. J.*, 1959, **38**, Dec., 4875–4965) This article contains both a review of the effect of As on the properties of mild steels and the results of tests on the effects of As on fusion-weld crack susceptibility, joint strength, ductility, and notch-toughness of API grade B plate.

Weld hardening of high strength steels and prediction of optimum welding conditions H. Kihara, H. Suzuki, and F. Kanatari (*Trans. Nat. Res. Inst. Met. Tokyo*, 1959, **1**, (1), 39–64) Weld thermal cycles in the heat-affected zones of various types of welds were made on arc-welded low-alloy high strength steels and a mild steel, using specimens tapering in thickness along the weld line. The results were used as a basis for constructing nomograms by means of which maximum hardness could be estimated in the heat-affected zone in any high-strength steel plate welded with any combination of welding current and rate, preheating temperature, and plate thickness (16 refs).

Non-destructive testing in welding W. A. Schall (*BEAMA J.*, 1959, **66**, Aug., 99–103) A general account of penetrant, X-ray, isotope, and ultrasonic methods.

The effect of the oxide content on the mechanical properties of a sintered joint between two metals W. Rutkowski (*Prace. Inst. Hutn.*, 1959, **11**, (5), 277–284) Investigations were carried out on the effect oxygen has on sintered joints of Cu, Fe, and W when added in the form of oxides. Physical properties were investigated as well as the electrical resistance created during joining. It was found that oxide addition had an advantageous effect on the quality of joint though the optimum quantity of additive was characteristic for each metal.

Effect of diffusible hydrogen on the mechanical properties of weld metal P. D. Blake (*Weld. J.*, 1959, **5**, Dec., 565–567) Machining treatments and heating at 150°C were used to remove most or all of the diffusible H_2. The effect on impact value was slight but H_2 was found to reduce ductility.

Hydrogen content of weld metal from coated electrodes and mechanical properties depending on duration of welding V. Gummich (*MIS*–5–58, translated into Russian; *Svarochnoe Proizv.*, 1959, (11), 44–45).

Calculating hot cracking resistance of high tensile alloy steel during argon-arc welding F. J. Wilkinson, C. L. M. Cottrell, and H. V. Huxley (*Weld. J.*, 1958, **5**, Dec., 557–562) Effects of composition were studied. The adverse effects of C, P, Si, and Ni were noted and their effect appeared to be reduced by Mn, Cr, Mo, and V. A formula for estimating hot crack sensitivity is given.

Fundamentals of brazing N. Bredzs and H. Schwartzbart (*PB*, 151655, 1958, Sept. 25, pp.57) The role of intermetallic compounds in brazed joints and the torsional properties of joints were studied in this report for June 1957–June 1958. Steel was brazed with Ag–Si, Ag–Zn, and Ag–Sn and previous work with Cu–Fe–B is reviewed. The relation of torsional strength to joint thickness was established.

Metallurgy of bonding in brazed joints. Part II. Migration of the filler metal into the base metal N. Bredzs and H. Schwartzbart (*Weld. J.*, 1959, **38**, Aug., 305s–314s) It is shown that diffusion at practical brazing temp. of the molten filler metal into the base metal lattice is very slow; the principal mechanism of filler metal migration through the filler metal–base metal interface being by a rapid process of grain-boundary penetration. This is discussed theoretically and practically.

Brazing stainless honeycomb T. A. Dickinson (*Met. Treating*, 1959, **10**, Nov.–Dec., 2–5, 40) Furnace, electric blanket, die quench, and salt bath brazing methods need by N. Amer. Aviation Inc. of Los Angeles are described.

Brazing by exothermic reaction (*Met. Prog.*, 1959, **76**, July, 114) Heating for brazing by an exothermic compound is used to make honeycomb panels of stainless steel, for repairing welded and brazed structures in the field, etc.

Adhesive tightens rail joints (*Iron Age*, 1959, **184**, Aug. 27, 92) A new thermosetting adhesive has been used to bond rail joints and prevent expansion and contraction due to climatic conditions.—A.G.

The properties and uses of metal adhesives R. A. Johnson (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6**, 141–148) The uses and advantages of metal adhesives are discussed, and the strengths and methods of application of 'Redux' and 'Araldite' are considered in more detail.

Heliarc offers better way to cut stainless steel Morrison Steel Co. (*Steel*, 1959, **149**, Sept. 7, 93) The use of an argon-hydrogen mixture to prevent oxidation of stainless steel during cutting is advocated. It is claimed that more complex shapes can be cut with a minimum of carbide precipitation.—A.G.

Basic recommendations on oxygen cutting of low carbon and low alloy steels (*Svarochnoe Proizv.*, 1959, (11), 45; abstract from translation into Russian MIS–17–59).

MACHINING AND MACHINABILITY

The machinability of metals and alloys E. Bickel (*Schweiz. Arch.*, 1959, **25**, Nov., 393–398) A general review on machinability of metals and alloys with special reference to the definition of what one has to understand by 'machinability' and in which direction future research should be conducted.—T.G.

Study of machinability of metals H. Takeyama and E. Usui (*ASME Trans. J. Eng. Ind.*, 1959, **81B**, Nov., 289–292) An experiment in the machinability of a series of metals (Al, Cu, brass, mild steel, alloy steel, and Meehanite cast iron) confined to the fundamental aspect of chip formation, in order to determine the relationship between machinability and the physical properties of a metal, is described and the data analysed and compared with the material testing data.—S.H.–S.

Study on machinability of metals H. Takeyama (*Rep. Gov. Mech. Lab.*, 1959, No.31, 87) [In Japanese] Parameters normally used to define machinability are not independent. From work with a specially-designed tool, a theory of machining based on the concept of tool-chip contact area is developed. Ernst's and Merchant's laws hold in the machining process. Practical means of reducing tool-chip contact area, e.g. use of cutting fluids or increase of speed, improve machining. Machinability is analysed in terms of the new theory, and the effects of machining parameters are examined. Tool-chip contact area has been related to tool life, surface finish and chip curl (35 refs).—K.E.J.

Speed and accuracy in machining (*Mech. World*, 1960, **140**, Jan., 15–18) An illustrated account of an exhibition of machine tools.

Which rake angle for carbide inserts? H. Frommelt (*Metalw. Prodn.*, 1959, **103,** Nov. 6, 1778–1779) Comparative tests to decide between the advantages of positive and negative rake angles are reported. General indications are given.

Leaded forgings machine easily (*Iron Age*, 1959, **184,** Sept. 3, 88) Improved machinability is claimed for Hi-Qua-Led leaded steel forgings with no deterioration in physical properties.

Large magnet core-manufacture and machining of 20-ton sections Joseph Sankey & Sons (*Iron Steel*, 1959, **32,** Nov., 525–529) The manufacture and processing is described of the 20-t sections of a 7000-t electromagnet core at the Manor Works, Wolverhampton for the Rutherford High Energy Laboratory at Harwell.

Numerical control machines tackle tough steel jobs at Rohr, cut tooling costs (*Western Metalw.*, 1959, **17,** Nov., 44–45) A description of electronic control equipment for manufacturing machines at Rohr Aircraft Corp., Chula Vista, Calif., is given.—T.G.

Three production short cuts at Boeing (1) New high speed stainless milling method, (2) Big freeze for B-70 wing panels, (3) Slippery metal foiled (*Western Metalw.*, 1959, **17,** Oct., 54–55) (1) liquid CO_2 used in high-speed milling operation increases rate from 15 in. to 180 in. per min. (2) Wing panels for B-70 Valkyrie bomber are subjected to temp. of −100°F. (3) $\frac{3}{8}$-in. dia. balls welded to high-strength metal alloy gripped material for test furnace where previously extensiometer clamps had slipped.

Machinability of sintered iron R. S. Jamison and E. Geijer (*Met. Powder Ind. Fed. 15th Annual Meeting*, 1959, 82–93) Test specimens were prepared of which structures are shown and tool life, surface finish, and tear point measurements were made. Effects of Cu, P, and S were observed.

Investigations into the effectiveness of compensating thermo-electric currents for reducing cutting-tool wear G. Engstrand (*Eng. Dig.*, 1959, **20,** Dec., 507–509; from *Trans. Roy. Inst. Technology, Stockholm*, 1959, **144,** *Mech. Eng. Series. No.5*, pp.9) Tests confirming that oxidation at the tip can be minimized by electrolytic means. The materials and conditions used are given.

Performance and wear characteristics of ceramic tools E. J. Krabacher (*Microtecnic*, 1959, **13,** (6), 291–297) It is shown that, under suitable conditions, longer tool life can be obtained with ceramic materials when milling cast iron at high cutting speeds than when using cemented carbides.

Ceramics as cutting tools English Steel Corp. (*ESC News*, 1959, **13,** Christmas, 4–6) An account of the development and properties of sintered Al_2O_3 'Sintox' tools.

Aspects of scientific investigations of metal machining in Rumania M. Popov, I. Mitrica, and E. D. Deciu (*Met. Constr. Mas.*, 1959, (12), 875–877) A report on the researches and investigation of the process in a few scientific laboratories.

Methods of approximate determination of turning speed of heat-resistant steels and alloys N. I. Tashlitskii (*Vestnik Mashin*, 1959, (10), 43–45) The methods described are based on determining cutting speed in machining the new heat-resistant steels and alloys by means of their chemical composition, mechanical properties, and from results of rapid strength tests, which will give good approximations when data are not available regarding machinability of the new heat-resistant steels and alloys.

Machining of metals at elevated temperatures H. Frommelt (*Ind. Heat.*, 1960, **27,** Jan., 94–102) Excess material from the welding of railway rails is removed with a specially designed milling machine with carbide cutters at approx. 1500°F. Power is reduced by up to 50%, finish is improved, and tool life is greatly increased. Examples are given of increased ease of machining Hastelloy parts at 350–400°F.—K.E.J.

Shear-zone size, compressive stress, and shear strain in metal-cutting and their effects on mean shear-flow stress D. Kececioglu (*Trans. ASME, J. Eng. Ind.*, 1960, **82B,** Feb., 79–86) The shear-zone in machining SAE 1015 118-Bhn seamless steel tubing over a wide range of conditions varies from $0{\cdot}95\times10^{-6}$ to $61{\cdot}5\times10^{-6}$ in^3. A relationship for the calculation is given. This is the only size effect important in metal cutting, no depth-of-cut size effect need be sought. Shear flow stress increases with decrease of shear-zone size.

Chip problem is eliminated with central vacuum system Murray Mfg. Co. (Syracuse, NY) (*Steel*, 1959, **145,** Aug. 31, 66) Difficulties due to the choking of machine tools and drill bushings have been overcome by the installation of a central vacuum cleaning system.

Multiple spindles take over production of camshafts R. H. Eshelman (*Iron Age*, 1959, **184,** Dec. 24, 54–55) A six-spindle multi-operation machine for making car-engine camshafts is described. Shafts are held between centres and driven from an offset hole so that the bearing journals can be machined.—D.L.C.P.

Oil reclaimed in first year pays for chip handling line Elastic Stop Nut Co. (*Steel*, 1959 **145,** Sept. 14, 168–169) The installation described automatically crushes machinings, extracts oil and pneumatically conveys the dry material to an overhead storage bin. Consumption of cutting oil is said to have been reduced by 83%.—A.G.

Tape positioning halves machining time L. E. Batchelor (*Metalw. Prodn.*, 1959, **103,** Nov. 27, 1923–1925) Control of a drilling machine with perforated tape is described in general terms.

Recent metal-removal developments with compressed-air carbon-arc process M. D. Stepath, H. B. Nelson, and W. J. Coughlin (*Weld. J.*, 1959, **38,** Aug., 755–759) The application of this process (which consists of melting with an electric arc and blowing away the molten metal with a high-velocity jet of air parallel to the electrode), to foundries, fabrication industries, and maintenance is discussed with examples.

Fast grinding forms small torsion bars B. C. Brosheer (*Metalw. Prodn.*, 1960, **104,** Feb. 3, 207–209) Ford Co. practice for rapid precision plunge grinding of power steering torsion bars is described.

What's going on in electromachining (*Steel*, 1959, **145,** Aug. 24, 80–83) American developments in electrospark and electrolytic machining methods are reviewed. The major fields of application are spark machining of dies and electrolytic tool grinding.—A.G.

The honing of drawn steel tubes G. Haasis (*Maschinenwelt Elektr.*, 1960, **15,** March, 91–93) The author describes briefly a new honing machine for drawn steel tubes as, for instance, for pit props. Tubes 1 m long and 100 mm in dia. are honed in two stages with a surface roughness of 1·5 in 6–8 min. Eccentricity of the tube after honing is less than 0·02 mm.—T.G.

Economic production of high-precision steel balls H. Gröbner (*Werkstattstechnik*, 1959, **49,** Sept., 497–501; from *Eng. Dig.*, 1959, **20,** Dec., 503–504) A new grinding process is described.

Drilling high-strength steels heat-treated to 330 to 560 Brinell hardness A. F. Gerds, C. T. Olofson, and F. W. Boulger (*DMIC–Memo–*31, 1959, Aug., pp.16; from *Nuclear Sci. Abs.*, 1959, **13,** Dec. 15, 2837) The need for adequate power and rigidity and the use of suitable drills is emphasized, and recommendations regarding drilling speeds and feeds are made.

Some applications of magnetostrictive load-cells P. Goudal and P. Vandamme (*Autom. Prog.*, 1959, **4,** Nov., 374–375) Cutting tool monitoring is included.

Spark-erosion de Havilland Engine Co. Ltd (*Aircraft Prod.*, 1960, **22,** Jan., 8–18) A fully illustrated account of the installation at Leavesden.

Spark machining Wickman Ltd (*Mech. World*, 1960, **140,** Jan., 36–37) An account of the Erodomatic machine.

CLEANING AND PICKLING

Automatic polisher 'super-finishes' shafts Ford AG (Cologne) (*Metalw. Prodn.*, 1959, **103,** Nov. 6, 1780) A note on a brush polishing Greif machine used for main gear shafts.

The effects of pressure in mechanical polishing C. A. Johnson (*AB Met. Digest.*, 1958, **4,** (3), pp.12) Specimen preparation with the heavy pressure technique is described.

Electrochemical polishing of the internal surfaces of tubes E. Stöckl (**Blech*, 1959, (10)) The difficulties of finishing the insides of tubes are noted and measured roughnesses before and after electropolishing are shown. The device used is illustrated and advantages are set out.

Progress in polishing. Recent developments in the field of barrel finishing C. J. Kellard (*Electropl. Met. Fin.*, 1959, **12,** Dec., 456–457). **Chemical and electrolytic polishing** F. H. Mills (457–458). **Some aspects of the use of liquid polishing compounds** S. J. Scouse (458–460; also *Met. Fin. J.*, 1959, **5,** Dec., 441–444). **Progress in machine polishing** J. H. Bryan and J. P. Dewar (460–461; also *Met. Fin. J., idem*, 437–441).

Lithographic sheets polished in the 'Silesia' Steel Works J. Zenkiewicz (*Prz. Techn.*, 1960, **81,** (4), 17) The process of polishing sheets to the standard required by the printing industry was, till recently, carried out privately in small workshops. Now the process is being carried out in the 'Silesia' works. There is considerable demand for this product in Poland, and the USSR is interested in any surplus. In view of this the author urges that the production in this field should be increased. For the present, production could be increased by modifying existing machinery and improving training facilities for operatives.

Electrolytic grinder demonstrated at Paris (*Metalw. Prodn.*, 1959, **103,** Nov. 13, 1833–1834) An account of apparatus shown at the Paris exhibition, with a note on costs.

Recent tests on economical cleaning of unalloyed low-carbon steel in sulphuric acid, using a wetting agent C. A. Fischer (*Wire Ind.*, 1959, **26,** July, 647–649, 676) The tests described indicate that, for accelerating the pickling process, synthetic wetting agents are preferable to natural ones such as rock salt. Anti-foaming additions are also recommended.

Shot-blast finishing Short Bros. & Harland Ltd (*Aircraft Prod.*, 1959, **21,** Dec., 416–419) An illustrated account of the Belfast plant.

Shot blasting of large surfaces Tilghman's Ltd (*Eng. Found.*, 1959, **25,** Aug., 34–36; from *Shipbuilding and Shipping Record*) A description of the Middlesboro and Sunderland shipyard installations.

Clean condition grit blastings T. Blackburn (*Weld. Met. Fabr.*, 1959, **27,** Dec., 472) The Open Vacu-blast equipment and its use in grit blasting of large nuclear power plant components for the establishment of 'clean conditions' is described, and its advantages over previous methods of site blasting on this and numerous other classes of work are specified The economic advantages of transportability and rapid assembly are stressed.—S.H.–S.

Grit-blasting with clean conditions (*Corros. Techn.*, 1960, **7,** Jan., 15, 24) The Major Mark II Vacu-Blast grit-blasting equipment, with closed-circuit operation, is described.

Chemical cleaning of oxidized nickel–iron–cobalt alloys for glass-to-metal seals N. Rain (*J. Sci. Instr.*, 1959, **36,** Nov., 479) Two solutions for the bright etching of the metal are described.

Descaling wire rods by shot-blast K. J. Sorace (*Met. Prog.*, 1959, **76,** July, 98–100) Rods of $\frac{1}{16}$ to $\frac{1}{4}$ in. dia. for drawing wire at 300 ft/min. are descaled in a new shot-blasting process. The blasting wheels are arranged at 120° round the strand, which passes twice. There are three 20 hp motors, and shot usage is 50 lb for a 4-h period. The finish is ideal for trapping drawing lubricant; costs are comparable with those of conventional methods; and the waste-liquor problem is eliminated.

Blast descaler with unique features used in new stainless steel plant Universal Cyclops Steel Co. (*Iron Steel Eng.*, 1959, **36,** Dec., 142) The special Rotoblast descaler handles two strands of steel simultaneously, and individual strand control permits the coils to pass through at different mill speeds. After setting, operation is entirely automatic.

Buff stainless for color match A. Zimmerman (*Iron Age*, 1959, **184,** Oct. 1, 84–85) The lighter the gauge of stainless steel the brighter is its surface. To overcome matching difficulties prebuffing of the stainless steel in coil form has been adopted.—A.G.

Metallic abrasives prepare surfaces for enamelling J. P. S. Jenner (*Bradley's Mag.*, 1959, Autumn–Winter, 10–11; from *Industrial Finishing*, 1959, Aug.) An account of the Wheelabrator process.

New products for pickling steel sheet, their use and choice, with particular reference to passivation and the preparation of surface treatments C. Hesse (*Corros. Anticorros.*, 1959, **7,** May, 178–184) Techniques for cleaning and pickling with a discussion of underlying principles, including jet and fusion treatments are described, and the use of inhibitors is discussed.

Ultrasonic setup speeds bar pickling Branson Ultrasonic Core (*Steel*, 1959, **145,** Oct. 19, 156, 159) A cog type conveyor moves hot-rolled round bars through a pickling bath agitated by ultrasonic transducers. Advantages claimed are process continuity and faster scale removal.—A.G.

Alkaline rust remover dissolves the rust without affecting the parent metal Turco Co. (*Austr. Mach. Prod. Eng.*, 1959, **12,** Sept., 27) The use of a proprietory product is described.

Studies of some inhibitors for pickling T. V. Mannarswamy, V. G. Paranipe, and S. Visvanathan (*Trans. Indian Inst. Met.*, 1959, **12,** Dec., 363–370; discussion 370) The effect of 0·01–4% of organic substance and inorganic halides as inhibitors in sulphuric acid pickling was determined. Proprietary organic substances were best but KI had an inhibiting action. KCl accelerated the rate of attack.

A modern continuous pickling process H. Moehring (*Draht*, 1960, **11,** Feb., 59–60) This is a summary of a paper in *Mitt. deutscher Emailfachleute*, 1959, **10,** 77–83, on the advantages offered by pickling with jets. As usual 8–12% H_2SO_4 is employed at temp. of 50–80°C. Concentration and temp. are interrelated. The pressure of the jets at the nozzles is 1·5–5 atm. Besides the more positive action during pickling, as compared with immersion pickling, it was found that a certain amount of $Fe_2(SO_4)_3$ is formed in jet but not in immersion pickling. This tervalent iron salt greatly accelerates the pickling process thus making the jet process even more advantageous.

PROTECTIVE COATINGS

The protection of steel against atmospheric corrosion by metallic coatings P. T. Gilbert (*Association Belge pour l'Etude l'Essai et l'Emploi des Materiaux (ABEM), joint meeting, Corrosion Group–Commission No.IV*, 2–3 June, 1954, pp.8) A general review of the use of metal coatings on steel is followed by a discussion of the application and properties of Zn and Al coatings, and reference to other metal coatings is made (24 refs).

An attempt to specify electroplating baths J. Glayman (*Corros. Anticorros.*, 1959, **7,** June, 265–268) Characteristics of plating baths and of the deposits formed are analysed.

Surface finishing and cladding of metals. Part I. Surface finishing of metals. Part II. Cladding of metals B. N. Das (*TISCO*, 1959, **6,** Oct., 260–271) Corrosion and corrosion prevention, metal coatings, phosphating, organic coatings, and protection against wear are considered.

Designing for simpler metal finishing techniques A. Walmsley (*Eng. Mat. Design.*, 1960 **3,** Jan., 18–21) Design to simplify polishing and plating operations is discussed.

The treatment of effluents A. H. Waddington (*J. Jun. Inst. Eng.*, 1959, **70,** Dec., 65–82) A general illustrated review of methods and control for a wide range of industries.

Review of local authority bye-laws on finishing trade effluents in Scotland Lord Meston (*Product Fin.*, 1959, **12,** Dec., 70–75) Practice and procedure in Edinburgh and Glasgow and the counties of Angus, Ayr, Forfar, and Renfrew as also of the Development Corporations of Cumbernauld, E. Kilbride, and Glenrothes are briefly reviewed.—S.H.–S.

The testing and examination of electrodeposits (Part I) R. Quarendon (*Product Fin.*, 1959, **12,** Dec., 90–93) The nature and measurement of lustre and brightness, bloom, and haze are defined with a graph of the lustre of Ni and Ag deposits after Egeburg and Promisel.

Research and investigations relative to the electrodeposition of chromium plate on steel W. H. Dancy, jun. (*NP*, 7654, 1959, June, pp.13; from *Nucl. Sci. Abs.*, 1959, **13,** Sept. 15, 2062) Bath concentrations were studied to improve adhesion.

Chromium plating baths containing sodium fluorosilicate. VI. Effects of anionic impurities on chromium plating T. Hayashi, S. Miwa, and S. Takagi (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1959, **8,** Dec., 841–845) Such anionic impurities as Cl^-, NO_3^-, and PO_4^{3-} decrease the current efficiencies and the bright-plating ranges. In baths containing Cl^- the base metals Cu, Ni, and Fe dissolve in the bath at low current densities in such amounts that the deposition of Cr ceases.—T.G.

Product finishing problems: (Part III) Electroplating F. H. Slade (*Product Fin.*, 1959, **12,** Sept., 84–89) A discussion which evaluates the fully and semi-automatic systems of hard Cr, Ni, and Cd plating as alternatives to hand operations.—S.H.–S.

Expanding commercial interest in nickel plating J. F. Thompson (*Product Fin.*, 1959, **12,** Oct., 88–89) The increase of this form of nickel consumption—at present 15% of the free world's nickel consumption—to a much higher market potential is predicted by Dr Thompson of International Nickel Co. of Canada Ltd in a letter to shareholders accompanying the interim report.—S.H.–S.

An investigation into the state of the surface of nickel and iron cathodes V. E. Past and Z. A. Iofa (*Zhur. Fiz. Khim.*, 1959, **33,** (6), 1230–1237) Oscillographic studies of potential drop on interrupting the polarization current are used to study the state of the cathode surface during polarization in acid and alkaline solutions. It is shown that only a small part of the area is covered with H_2 ionizable at the given potential.

Dip plating processes D. J. Fishlock (*Mech. World*, 1959, **139,** Nov., 480–484) A comprehensive review of displacement, contact, and chemical plating with an account of the Kanigen process and a comparison with dull electroplated Ni.

Nickel-plating in the 'Lambretta' (*Product Fin.*, 1959, **12,** Nov., 56–57) The work performed at the Milan factories of Innocenti, Soc. Gen. per l'Ind. Metallurg. e Mecan. by an automatic plating machine on more than 30 parts of the 'Lambretta' motor scooter and the sequence of 22 operations is briefly described.

Studies of the throwing power of plating baths. II E. Raub (*Mitt. Forschungs. Blechverarbeitung*, 1960, Feb. 5, 38–46) The throwing power of various Cu and Ni plating baths (Watts, bright, and cyanide) was studied on five shapes of sheet-metal sections. The mechanisms responsible for variations in plating thickness, such as convection of the electrolyte on a macro- and micro-scale, are discussed and the results of the experiments presented in tables and graphs.—T.G.

The present position of hot-dip galvanizing R. Haarmann (*Corros. Anticorros.*, 1959, **7,** April, 146–152) Statistical data showing the growing importance of hot-dip galvanizing are followed by an account of the technical development of the process, the properties of the coatings, and the use of a combination of paint and a galvanized coating.

The jobbing galvanizing shop H. Dewert (*Metalloberfläche*, 1960, **14,** Feb., 52–55) The requirements in equipment and plant for a jobbing galvanizing shop, its economics, and the necessity for time and motion studies are briefly discussed and few examples are quoted of structural parts that are difficult to treat in the galvanizing bath owing to their dimensions.—T.G.

Hot-dip galvanizing in continuous strip operation J. Lasbleis (*Rev. Mét.*, 1959, **56,** Dec., 375–386) A general discussion of the protection of iron against corrosion by Zn is followed by a review of the advantages of the Sendzimir process in producing good adhesion of the Zn coating, and a description of the continuous galvanizing line at the Montataire works.

The galvanizing of sheet and wide strip R. Haarman (*Metalloberfläche*, 1960, **14,** Feb., 49–52) After a statistical survey of the consumption of galvanized sheet and strip the author describes the new Sendzimir galvanizing line at the August-Thyssen Hütte in Germany for wide strip. The Zn bath is alloyed with Al.—T.G.

Electrolytic deposition of Zn in presence of small quantities of antimony and cobalt D. P. Zosimovich and H. F. Bogatova (*Zhur. Fiz. Khim.*, 1959, **33,** (6), 1324–1327) Addition of 0·05 mg/l Sb shifts the polarization curve to more electronegative values and higher concentrations shift it to the electropositive side increasing H_2 evolution. Co has similar effects. Small quantities of these ions appear to act as surface-active substances.

Galvanizing, painting, and corrosion P. Morisset (*Corros. Anticorros.*, 1959, **7,** May, 203–220) Systematic accelerated corrosion trials are described on galvanized sheet, and on sheet galvanized and treated with six types of paint—zinc, tin, glycerophthalic, phenolic, bituminous, and wash-primer with a finishing coat. Particular aspects studied included: corrosion resistance as a function of amount of galvanized coating; advantages of a zinc undercoat; paint adherence and quality; influence of type of paint and number of coats; nature of corrosion attack (9 refs).

Tinplate flow-melt equipment at the Velindre Works of the Steel Company of Wales J. T. Bentley and R. Quinnen (*English Electric J.*, 1959, **16,** Dec., 41–46) In the electrolytic tinplate line at Velindre, the strip leaves the plating section with a matt surface. To obtain the bright surface required for the final product the tin is melted for a short time. This is done by ac resistance heating in the so-called flow-melt tower while the strip is travelling at speeds up to 1250 ft/min. The heating and control system is described.—T.G.

Examples of fixed value and programme control of electric resistance furnaces W. Weitbrecht (*Elektrowärme*, 1959, **17,** July, 251–254) Several examples are given of the control of batch and continuous type furnaces, and it is shown that modern control equipment can be applied to a wide range of installations. The use of magnetic-bias control elements in a wide-strip tinning line is described.

The effect of cadmium plating on SAE 4340 steel in the presence of stress concentrations at elevated temperatures E. M. Kennedy, jun. (*WADC–TR–58–108* (Part I), *AD–151075; PB–131814*, 1957, Dec., pp.40; from *Nucl. Sci. Abs.*, 1959, **13,** March 15, 393).

Anticorrosive treatment National Research Corp. (*Aircraft Prod.*, 1959, **21,** Dec., 415) An Al coating process is mentioned.

What is new in the aluminizing of iron V. I. Karasevich and V. E. Prikhod'ko (*Tsvetnye Met.*, 1959, (10), 68–75) A method is described of producing aluminized iron tape which increases productivity by a small factor, reduces cost price and makes possible a 20-fold increase in weight of the work pieces. Under the action of the reactive diffusion of iron an intermediate core of $FeAl_3$ forms in the Al coating, which does not depend on the carbon content in the steel blank. This layer forms with 0·03% as well as with 0·12%C steel.

Linseed oil as an organic flux in hot-dip aluminizing of steels S. M. Arora, P. K. Gupte, and B. R. Nijhawan (*NML Techn. J.*, 1959, **1,** Aug., 9–16) Linseed oil can be used instead of glycerol and leaves a clean surface permitting diffusion of Al. Effects of small additions of Ti, Ni, and Mn to the bath are observed, and heat resistance, corrosion resistance, and formability are examined.

Science for electroplaters: 49, 50 copper plating L. Serota (*Met. Fin.*, 1959, **57,** July, 72–74, 81; Aug., 72–73, 75; Sept., 85–88). **51. Copper bath analysis** (Oct., 77–80). **52. Copper plating–IV** (Nov., 80–83) Characteristics of the fluoborate process are given.

Study of the structure of a tungsten–cobalt electrodeposit on a 0·06% carbon steel S. Yoshioka, H. Yamamoto, and A. Hoshino (*Nippon Kinzoku*, 1959, **23,** Feb., 132–134) [In Japanese] The 45:55 W–Co alloy layer electrodeposited on a 0·06%C steel was heat-treated in various ways and its structure examined by X-ray diffraction. It was found, *inter alia*, that adherence of the alloy layer was markedly improved by a Ni flash followed by vacuum annealing.—T.G.

Contraction stresses in metal coatings obtained by projection: measurements of

deformation in thin mild steel strip W. E. Stanton (*Corros. Anticorros.*, 1959, **7,** June, 247–252) A paper read at the 11th International Conference on Metallization, Birmingham, 20 Sept.–3 Oct., 1958, and published in *Met. Ind.*, 1958, **86,** Dec. 19, 509–511).

Cold phosphating (*Mech. World*, 1959, **139,** Nov., 466–467) A general account of the Farbewerke Hoechst AG processes lately introduced into England.

Pioneers of anti-corrosion treatment M. Schofield (*Product Fin.*, 1959, **12,** Nov., 74–75) Tributes to the 50-year-old phosphating patent of Thomas Watts Coslett and to Sherard Osborn Cowper Cowles, the pioneer of sherardizing, and also to Guy Dunstan Bengough, the pioneer of anodizing.—S.H.–S.

Automatic phosphating line pays off in first year Timken Roller Bearing Co. (*Product Fin.*, 1959, **12,** Sept., 75–77) The equipment of the Timken Roller Bearing Co. of Canton, Ohio, in which radio-controlled cranes carry large mill roller bearings through a phosphating line is described.—S.H.–S.

The use of oil bitumen for the protection of buried pipelines E. Leclerc and M. Goldstein (*Association Belge pour l'Etude, l'Essai et l'Emploi des Materiaux (ABEM); joint meeting of the Corrosion Group and Commission No.IV*, 2–3 June 1954, pp.11) Topics discussed include: general considerations on the use of bitumen for this purpose, examination of the processes for controlling the product, and a critical study of the main objections raised to its use.

Wrapping for protection with petrolatum-based tape W. A. Brewis (*Corros. Techn.*, 1960, **7,** Jan., 9–11) Disadvantages of a bitumen coating include its tendency to cracking, and advantages of grease-type and other wrappings, particularly for exposed or buried metal parts, are discussed.

Patterning plastic-coated steel: inspecting embossing (*Product Fin.*, 1959, **12,** Dec., 84–85) The manufacture of a number of commercial products from vinyl-coated steel developed by US Steel at Pittsburgh, USA, is briefly described.—S.H.–S.

Artbrite P.V.C.-coated steel sheet Richard Thomas & Baldwin Ltd (*Machinery*, 1959, **95,** Dec. 23, 1384–1349) A brief description of the material.

New look comes to steel (*Met. Progr.*, 1959, **75,** March, 126–127) The properties, including decorative value and dielectric strength, the cost, the variety of colours and textures, fabrication, and assembly of vinyl-coated steel are briefly discussed.—T.G.

Epoxy resins gain ground as partners of metals G. F. Kingsley (*Iron Age*, 1959, **184,** Dec. 31, 39–41) Epoxy resins are mostly used for protective coatings, but their use as a tool material is rapidly expanding.—D.L.C.P.

Vitreous enamelled cast iron (*Bradley's Mag.*, 1959, Autumn–Winter, 8–9) A brief account of production and common defects.

Vitreous enamel—the lifetime finish K. Jones (*Product Fin.*, 1959, **12,** Sept., 78–79) A cursory glance at the 2000-year history of the industry.—S.H.–S.

Vitreous enamelling cast iron hollow-ware (*Product Fin.*, 1959, **12,** Sept., 68–74) The work of the GWB electric furnace installation of Izons & Co. Ltd of West Bromwich, Staffs. is briefly described.—S.H.–S.

The oxidation of steel during the firing of boron and boron-free ground enamels G. I. Belyaev (*Zhurn. Prikl. Khim.*, 1960, (1), 94–101) The corrosion of steel depends on the chemical composition and basicity of the fused silicate mass. With an increase of O_2 potential of the glass and its basicity, corrosion increases. In boron-containing coatings, which are more acid, the quantity of iron in the lower stage of oxidation is appreciably larger than under coatings without boron.

A rapid method of determining comparative subsieve fineness of milled porcelain enamels E. E. Bryant and G. H. Johnson (*Ceram. Bull.*, 1959, **38,** Nov., 649–652) The method is suitable for shop control. The average specific gravity of portions in a settling column is measured.

The problem of painting rusty steel J. E. O. Mayne (*J. Appl. Chem.*, 1959, **9,** Dec., 673–680) The seasonal variation of ferrous sulphate in rusty specimens exposed at Cambridge and its effect on seasonal painting are discussed.—

Sealing castings Ford Motor Co. (*Autom. Eng.*, 1959, **49,** Oct., 398–401) A description of the fully mechanized dip-painting plant at Dagenham.

Automatic car body building conveyor system in new paint, trim and assembly building of the Ford factory Ford Motor Co. (*Mech. World*, 1959, **139,** Dec., 518–520) An illustrated account.

Finishing tubular steel furniture P. Almand (*Product Fin.*, 1959, **12,** Sept., 50–57) Systems used by Cox & Co. (Watford) Ltd in painting and finishing motor seats, screens, and tubular furniture are described.—S.H.–S.

The mechanism of the prevention by paints of corrosion J. E. O. Mayne (*Association Belge pour l'Etude, l'Essai et l'Emploi des Materiaux (ABEM); joint meeting, Corrosion Group-Commission No.IV*, 2–3 June, 1954, pp.7) Mechanisms of corrosion inhibition by paint are described; they may modify the anodic reaction if the pigment is metallic, soluble, or basic, but they are too permeable to water and O_2 to inhibit the cathodic reaction. They function in general by their high electrolytic resistance (24 refs).

Electrical measurements in the study of immersed paint films on metal F. Wormwell and D. M. Brasher (*Association Belge pour l'Etude, l'Essai et l'Emploi des Materiaux (ABEM), joint meeting, Corrosion Group-Commission No.IV*, 2–3 June, 1954, pp.10) By means of electrical measurements on paint films on immersed specimens, the paint life, water absorbed and the influence of various factors on film breakdown were determined. Capacitance—time and water—uptake/time curves showed that osmotic pressure and ionic concentrations influence rate of paint breakdown (33 refs).

CLAD SHEET AND HARD FACING

Hard surfacing strikes back (*Iron Age*, 1959, **184,** Sept. 3, 83) The technique of hard surfacing worn blast-furnace bells and hoppers with weld deposits of special alloys is described. The accurate seating so obtained makes possible the use of higher top pressures.—A.G.

Diffusion chrome coatings on white-heart malleable iron W. Sakwa and J. Czepiel (*Prz. Odlewn.*, 1960, **10,** (1), 16–21) The article gives a general introduction to the problem on the basis of past work and the authors' original experiments. It is found that the formation of chrome acid-resistant coatings during the annealing of cast iron is possible and gives good results if the correct atmosphere is maintained during annealing, that the coatings display a rather high hardness and adequate acid resistance, and that the mechanical properties of cast iron treated in this way are somewhat inferior to those of cast iron annealed in the normal way.

Plate life into your dies (*Iron Age*, 1959, **184,** Aug. 27, 86–88) Reasons for the wear and failure of hot working dies are discussed. The use of thermally bonded Ni or W plate is advocated to improve die life. The method of application and some examples are described.

Inlay makes Ti-clad vessels possible R. B. Norden (*Chem. Eng.*, 1959, **66,** Nov. 2, 118, 120, 122) Attachment to Ti to steel by a silver joint is explained.

Tests on the permeability of the components of water through clad plate W. H. Moyer (*BW-5405*, 1951, Feb., pp.19; from *Nucl. Sci. Abs.*, 1959, **13,** Sept. 15, 2059) Apparatus is described for measurement up to 650°F and pressures of 2500 psi for SA212, AISI347, and SA212 clad with AISI347.

Navy engine maintenance costs slashed 85% by hard-surfacing alloy (*Western Metalw.*, 1959, **17,** Sept., 52–53) The work of spray-welding, and the use of Colmonoy No.6 hard-surfacing alloy in cutting reclamation—overhaul cost on valves, are described.—S.H.–S.

POWDER METALLURGY

The production of iron powder by gaseous reduction M. R. Kalyanram (*J. Metallurg. Club*, 1958–59, (11), 39–44) Work on haematite ore at the Jamshedpore plant of Tata Iron & Steel Co. Ltd is described, and results of 55 experiments at 600–800°C are tabulated. Increased gas rates give increased reduction.

The increase of iron reactivity obtained by the thermal reduction of ferric oxide under low hydrogen pressure J. Hui and A. Boullé (*Compt. Rend.*, 1959, **249,** July 15, 283–285) Results showing the increased reactivity of powdered iron produced in this way are reported.

Metal sinterings T. P. Barbicane (*Met. Ind.*, 1959, **95,** Aug. 21, 38–40) Choice of sintering temp., dimensional stability, hardness, and tolerances are discussed.

Hot pressing powders in England A. Blainey (*Met. Prog.*, 1960, **77,** Jan., 104–108, 178, 190, 192) Techniques for hot pressing Be and cermet powders are described.

Sizing and coining metal-powder parts J. Haller (*Machinery*, 1959, **95,** Sept. 30, 648–650) Sizing to close tolerances and coining to increase density are described. Presses are described producing a 10% increase in density.

Compacting presses and tooling systems J. J. Kux (*Prec. Met. Mold.*, 1959, **17,** July, 28–31) The design and operating features of simple motion, multiple motion, and hydraulic presses for compacting metal powders are discussed in relation to tooling systems.—A.G.

On the sintering of W–Ni–Cu heavy metals S. Mäkipirtti (*Acta Polytech. Scand.*, 1959, *Chem. including Met. series* No.5, *Mech. Eng. Series* ME 7, pp.71) [In English].

Steel strip from ore without melting (*Met. Prog.*, 1959, **76,** Aug., 86) The process developed by Republic Steel Corp. is described, in which Fe powder is compressed into strip.

The production of sheet and strip from metal powders G. Naeser and F. Zirm (*Met. Rev.*, 1959, **4,** (14), 179–187) The powder rolling process is reviewed with a table of Patent numbers.

Perfected and practical methods of processing powder into commercial strip R. A. Smucker (*Iron Steel Eng.*, 1959, **36,** July, 118–124) A process for the continuous production of hot-rolled strip from metal powders is described; the application given is non-ferrous, but the process is said to be suitable for most metal powders.

New pilot processing plant designed for heat treating and agglomeration W. A. Shockley (*Eng. Min. J.*, 1959, **160,** Sept., 98–101) A description of the process pilot plant, 1/50 commercial size, set up at the Allis-Chalmers Manufacturing Co. at Carrollville, Wis. to investigate problems connected with sintering, heat treatment, or processing of a number of raw materials.

Fiber Metallurgy R. H. Read (*Steel*, 1959, **145,** Aug. 10, 126–128) A felted product made from metal fibres analogous to paper-making is described. The fibres 0·001–0·02 in. dia. and 0·01–1·0 in. long are deposited from a slurry in a porous mould and sintered in a reducing atmosphere. Possible uses are indicated.

Paper making techniques applied to metals P. T. Imber (*Metalw. Prodn.*, 1959, **103,** Nov. 27, 1925–1926) A general introduction to fibre metallurgy.

Measurements of pressure effect on the Seebeck coefficient of powder compacts A. P. Young, P. B. Robbins, W. B. Wilson, and C. M. Schwartz (*Rev. Sci. Instr.*, 1960, **31,** Jan., 70–71) A high pressure cell (up to 20000 atmos.) is described.

Fabrication, properties and use of fritted mechanical pieces R. Hauser (*Age Nucléaire*, 1957, Nov.–Dec., 48–54; from *Nucl. Sci. Abs.*, 1959, **13,** Mar. 15, 395) A brief survey with a forecast of future development.

Relation between long-term resistance of metal ceramic iron specimens in the α- and γ-phases, under load and an applied stress B. Yu. Pines and A. F. Sirenko (*Doklady AN*, 1959, **129,** (2), 310–313) Experiments were carried out on metal ceramic specimens 30 mm long of 3×3 mm cross-section composed of iron powders of average size ~30 μ, average porosity ~20%, but final porosity varied. Annealed 20 h at 900° and then 15–20 h at 1200° the final porosity was 3–10%. Long-term resistance was determined at 600, 800, 900, 1000, and 1100° *in vacuo* (10^{-4}–10^{-5}) and no traces of oxidation could be discovered. Results are given in graphs.

Making compacts by explosive forming E. W. LaRocca (*Met. Prog.*, 1959, **76**, Sept., 85–86) An explosive force, acting through pistons, compresses powders (Co, Ti fillings) and solids (graphite discs).

Try hot explosive-compacting for sintered powder products A. Cross (*Iron Age*, 1959, **184**, Dec. 24, 48–50) An investigation into the properties of explosive-formed parts is reported. This process involves firing an explosive charge over metal powder at above its recrystallization temp., in a die. Lead powder was used in the investigation so that room temp. could be used. Product strength increases with explosion pressure, but an optimum particle size was found. Product-size conformed closely to die-size so that it should be possible to make finished parts.—D.L.C.F.

The explosive press as a research tool in material behaviour and forming E. W. LaRocca and J. Pearson (*Navord Rep.* 5880; *PB* 151844, 1958, May 12, pp.13) Powdered materials were studied in small single and double action presses. Pressures are estimated as several million lb/in^2. Shaping is possible by modifying the piston faces.

Iron carbon system in powder metallurgy. II. Effects of atmosphere composition U. Gummeson (*Prec. Met. Mold.*, 1959, **17**, Dec., 36, 50) A brief review of sintering atmospheres and their effects on decarburization.

A new basis for an inspection method for sintered metal components B. Bovarnick (*RPL*, 41/2; *PB* 151133, 1958, March, pp.92) In the method described, electrochemical potential was measured and compared with the properties of the sintered materials. Good correlation was found between strength and potential, and it is concluded that potential is a suitable measure of extent of sintering and strength attained, and that the method can be developed as a routine industrial acceptance test. Iron compacts were used (94 refs).

Testing of iron powders for powder metallurgy Y. Nanya and E. Hayashi (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1959, **8**, Sept., 616–625) The authors describe the testing of a variety of iron powders including the behaviour of the powders during compacting and sintering. The test results are reported and a number of testing methods adopted in these experiments are proposed as a tentative method for the quality test of iron powders for powder metallurgy.—T.G.

FERRITES, CERMETS, AND CARBIDES

The electrical resistivity of oxygen-deficient nickel ferrite R. Parker and H. Lord (*Proc. Phys. Soc.*, 1959, **74**, Dec., 793–795) A letter.

The magnetocrystalline anisotropy of cobalt-substituted manganese ferrite R. F. Pearson (*Proc. Phys. Soc.*, 1959, **74**, Nov. 1, 505–512)

Some properties and metallography of steel-bonded titanium carbide M. Epner and E. Gregory (*Trans. Met. Soc. AIME*, 1960, **218** Feb., 117–121) These materials with up to 54% by wt. TiC can be annealed and hardened like alloy steels. They can be machined after annealing.

PROPERTIES AND TESTS

Research in the field of pure metals A. Ferro, G. Montalenti, and G. Venturello (*Met. Ital.*, 1959, **51**, Nov., 530) The writers describe studies now being carried out at the Istituto Galileo Ferraris of Turin for the establishment of a method of preparing pure iron. By this method copper, cobalt, and nickel impurities can be almost completely eliminated. A description is also given of research into the preparation of highly permeable iron and into the significance of impurities in the recrystallization of iron.

Design of laboratory furnaces P. L. Start and M. W. Thring (*J. Sci. Instr.*, 1960, **37**, Jan., 17–27) Heat balance in furnace design and the principles of arc, arc-image, induction, election-bombardment, resistor-heated, and gas-fired furnaces are discussed with a table of refractory tubes, resistor materials, and insulating materials. The control of small furnaces is also outlined.

Standards of measurement for engineering H. Barrell (*Quality Eng.*, 1960, **24**, Jan.–Feb., 2–12) Work at Teddington is described. Indentation hardness is discussed and the establishment of a standard for the Vickers scale is described.

Quality in engineering manufacture F. Nixon (*Quality Eng.*, 1960, **24**, Jan.–Feb., 13–23) Experience with Rolls-Royce Ltd, is described with various case histories.

Survey of metrology (*Draht*, 1960, **11**, Jan., 5–12) A survey of micrometers—mechanical, photo-electric, and optical types—and other optical instruments used in metrology as shown recently at the sixth EWA at Paris.

Fluctuations in the service life of machine components and units R. V. Kugel' (*Vestnik Mashin.*, 1959, (5), 9–16) Since it is impossible to foresee with any precision the service life of components and entire machines it is advisable to give the highest 'minimum' service life which could be guaranteed for say 97–98% of the units and to ensure easy replacements when needed.

Structural changes in the steel during riveting and their effect on strength and contraction on the rivets A. Krisch and A. Rose (*Stahl Eisen*, 1960, **80**, Feb. 18, 210–219) When using rivets of steel St 44 for hot riveting, the working takes place in the austenite phase, but structural changes of the steel occur during the accelerated heat extraction by the cold plates to be joined. The rivet becomes harder as a result of this cooling. The structural change may in this case occur at temp. at which the working of the rivet is already complete. The elongation connected with the $\gamma \rightarrow \alpha$ transformation counteracts, in this case, the contraction which is required for a good joint, i.e. the rivets may be quite loose when cold.—T.G.

Austenitizing behaviour and rapid life test of drawn wires for bearing balls M. Ueno (*Trans. Nat. Res. Inst. Met., Tokyo*, 1959, **1**, (1), 22–26) Effect of ingot size and different raw materials on the life of five types of wire, showed no appreciable influence of ingot size, but an addition of V gave improved life. Effects of austenitizing temperature were investigated.

Instrumentation as applied in metallurgy. Introduction J. Convey (*Canad. Min. Met. Bull.*, 1959, **52**, Nov., 670–706). **What instrumentation can offer the metallurgist** J. F Hornor (671–675) An outline of measurement, presentation of data, and automatic control. **Instrumentation at Algoma Steel Plant** A. K. Bayles (675–680) Coke oven, blast-furnace, OH, and converter control, and soaking and reheating are briefly reviewed. **What does the ore dressing metallurgist want of instrumentation** D. B. Smith (693–695) Questions of the data to be expected and control to be effected are posed. **What an extraction metallurgist wants from instrumentation** D. A. Fraser (695–697). **Instrumentation for the physical metallurgist** M. Armstrong (698–699). **General Discussion** (699–706).

Research and instrumentation A. V. Astin (*Blast Fur. Steel Plant*, 1959, **47**, Nov., 1183–1185) An abridged report of the address at the dedication of the Research and Development Centre of Leeds and Northrup Co. in Sept. 1959.

Quality control at Pittsburgh Works G. A. Jedenoff (*Iron Steel Eng.*, 1959, **36**, Dec., 127–132) The techniques used at the Pittsburgh Works of Columbia-Geneva Steel Division of United States Steel Corp. are described.

Tracing of surface defects on steel products by artificial blowholes K. Kajiyama (*Tetsu to Hagane*, 1959, **45**, March, 307–308).—K.E.J.

Methods of determining surface roughness M. K. Testerman (*WADC–TR*–58–230; *AD*–155828, 1958, June, pp.48; from *Nuclear Sci. Abs.*, 1959, **13**, March 15, 394) Twelve techniques of measurement are mentioned. A capacitance method was used under various conditions and studies on a radioactive method were begun.

Measurement of surface roughness of cold-rolled steel strip and drawn steel wire and rod W. Lueg and U. Krause (*Stahl Eisen*, 1959, **79**, Dec. 10, 1837–1843) The difference in the surface roughness of rolled and drawn steel products is explained and the difficulties connected with surface-roughness measurements on wires discussed. It was noticeable that the results of surface roughness measurements of the same area were scattered widely when determined by apparatus of different makes. It was also found that the surface roughness of drawn products cannot be resolved by the pointers commonly in use.—T.G.

Surface roughness of hot and cold drawn steel tubes. III. Development of surface quality during cold working H. Mühlenweg (**Stahl Eisen*, 1959, **79**, Dec. 10, 1844–1852) The effect of cold working in the various stages of processing of steel tubes on the surface quality was studied. The relations between shape of die, initial surface quality, reduction in diameter, and wall thicknesses are discussed. It was found, *inter alia*, that any roughness of the die has little effect on the surface quality of the tube, but requires a better lubricant, and that grain size of the steel and structure of the scale have a decisive influence on the final surface quality.—T.G.

Growth of single crystals of stainless steel R. D. Leggett, R. E. Reed, and H. W. Paxton (*Trans. Met. Soc. AIME*, 1959, **215**, Aug., 679–680) A technique is described for the production of single crystal ingots of Fe–20, Cr–20, Ni. By a small modification, bicrystals can be grown and orientation is controllable by the use of seeds.—A.G.

The flow of steel in tubes subjected to triaxial stresses S. Lesák (*Hutn. Listy*, 1959, **14**, (10), 853–856) Equipment for testing tubes at pressures and temperatures of steam superheated to levels used in power plant, and higher, is described. Preliminary results designed to check creep data under conditions of triaxial and uniaxial stress in tests up to 600°C lasting up to 2000 h are reported.—F.F.

Replica method for examining surface profiles A. P. Young and B. H. Clegg (*Rev. Sci. Instr.*, 1959, **30**, June, 444–446) The optical microscope is used, though the method would apply to the electron microscope. Gear tooth surfaces have been examined.

The principles of plastic deformation V. G. Pananjpe (*TISCO*, 1959, **6**, Oct., 191–200) Slip, twinning, and grain rotation are considered in terms of dislocation theory, and the stress-strain relationships for plastic deformation are discussed.

Thermal stresses in design: 15: Strain gage applications S. S. Manson (*Mach. Design*, 1959, **31**, Nov. 12, 183–189) The theory of the strain gauge is set out for low, medium, and high temp. and over the plastic range. The methods of using the gauges are outlined.

Residual stress measurement as a means of distinguishing manufacturing methods G. Sachs and V. Weiss (*Microtecnic*, 1959, **13**, (6), 275–276).

Measurement of internal stresses in metals and alloys A. B. Chatterjea (*TISCO*, 1959, **6**, Oct., 280–289) This review deals briefly with the way in which internal stresses arise, and then describes the methods by which they may be measured. The mechanical methods are dealt with in detail, and the electrical, magnetic, and X-ray methods are also considered.

Brittle lacquers: An aid in stress and strain analysis H. Motzfeld and S. Brach (*Technik*, 1960, **15**, Feb., 72–75) The merits of the use of brittle lacquers in stress analysis are discussed, compositions of such lacquers and their handling are given and their behaviour under tension, bending, and torsion described.

Measurement of residual stresses by wire strain gauges (Study of carburized steel for ball and roller bearing material). III T. Yoshida (*Nippon Kinzoku*, 1959, **23**, Feb., 94–96) Residual stresses resulting from case-hardening were measured by resistance strain gauges and the effect of case depth on surface stresses determined. The surface stress was a minimum for medium size case depths.

The mechanical damping of steels after hardening and tempering E. Scheil, E. Wachtel, and G. Gurbaxani (*Arch. Eisenh.*, 1959, **30**, Aug., 497–501) Damping characteristics of two dead mild steels, two carbon steels containing 0·48 and 0·95%C, and an Fe–Ni alloy with 9·44%Ni were investigated. The damping maximum observed in high C steels at 200°C after quenching from the γ-region and the effect of tempering above 200°C on this maximum are discussed, and the influence of residual deformation and martensite formation in causing the maximum are examined.

On the elastic moduli of polycrystals in relation to the constants of monocrystals R. Colombo (*Met. Ital.*, 1959, **51**, Oct., 466–467) The values are given of the elastic constants of mono- and polycrystalline metals and of two alloys belonging to the cubic system. Reference is made to the Voigt and Reuss hypotheses and to the so-called 'law of the average' the unreliability of which is well known.

Investigation of the relationships between the embrittling factors and micro- non-uniformity of the plastic deformation of steel B. B. Chechulin (*Fiz. Met. Metallov.*, 1959, (4), 607–613) The results of measuring the micro- non-uniformity of the plastic deformation of polycrystalline metals obtained by two different methods show good correspondence. The grain size affects appreciably the non-uniformity of the deformation between grains. The greater the size of the grains the greater the non-uniformity of the plastic deformation. An increase in the rate of deformation and a reduction of the temp. have little effect on this micro- non-uniformity within the limits of the separate grains.

The dependence of internal friction on frequency J. Wilks (*Phil. Mag.*, 1959, **4**, Dec., 1379–1381) A model with dislocations anchored at both ends is examined and the idea of Thompson and Holmes that the dislocations may be freed in certain circumstances is taken into account. There appear to be insufficient experimental data.

The character of the deformation on the surface in plastic flow I. M. Gryaznov (*Doklady AN*, 1959, **126**, (6), 1250–1253) On stretching Armco iron, carbon steel, copper, and brass, the appearance of bands is accompanied by rotation of the grains. The majority of these bands form on the surface during the deformation and these grow and new bands form only in small numbers. It has been confirmed that the displacement and rotation of the grains cannot occur without displacement of the grains in depth.

Study of high manganese steel: on the plastic deformation of cone-shaped specimens H. Fujii (*Tetsu to Hagane*, 1959, **45**, March, 355–357).—K.E.J.

Contributions of the physics of metals to the knowledge of the structural phenomena F. Gatto (*Met. Ital.*, 1959, **51**, Nov., 521–524) The principal contributions of the modern theories and techniques of the physics of metals to metallurgy are described with particular reference to those relating to metal fatigue and the properties of alloys of the cold-working, solution quenching, phase quenching, and multi-structural types.

New experimental confirmations of the theory of dislocations A. R. Weill (*Mém. l'Artillerie Franc.*, 1959, **33**, (129), 687–713) A detailed illustrated review.

Mobility of edge dislocations in silicon iron crystals D. F. Stein and J. R. Low, jun. (*J. Appl. Phys.*, 1960, **31**, Feb., 362–369) A method of measuring velocity of new dislocations produced by scratching as a function of stress is described. Velocities of 10^{-7} to 10^{-3} cm/sec. were measured in 3·25%Si iron. The temp range 78–373°K was covered. Mechanism is considered.

Point-like defects in metals, their formation and energies of migration F. G. Fumi (*Met. Ital.*, 1959, **51**, Nov., 531–532) After summarizing the elementary mechanisms of diffusion into solids the author explains how lattice defects, particularly point-like ones (vacancies or intergranular) appear in the most simple patterns of atom diffusion into metal. In order to calculate the relative importance of various types of defects for the diffusion of atoms in the metal one must know the energy of migration. Some methods used for the calculation by experiment of these and of energies of formation are discussed.

Order-disorder transformations in iron–aluminium alloys H. J. McQueen and G. C. Kuczynski (*Trans. Met. Soc. AIME*, 1959, **215**, Aug., 619–622) A part of the equilibrium diagram between 20 and 30% in iron has been revised on the basis of dilatometric data. Isothermal ordering rates for the 25%Al alloy are approximately the same for each disordering temperature indicating that the process is one of nucleation and growth.—A.G.

Theory of order in Fe_3Al alloy K. F. Wojciechowski (*Acta Phys. Polon.*, 1959, **18**, (1), 15–20) [In English] A statistical theory is developed taking into account atoms other than nearest neighbours. It is shown that the interaction energy of third neighbourhood atoms is about half that of second.

Note on the change in stored energy produced by reversed deformation A. S. Iyer and P. Gordon (*Trans. Met. Soc. AIME*, 1959, **215**, Aug., 729–730) Deformation experiments on high purity copper confirm Polakowski's prediction that the stored energy produced by deformation should be reduced during the initial stages of subsequent deformation carried out under conditions which produce work softening.—A.G.

The flow stress of iron and its dependence on impurities G. Schoeck and A. Seeger (*Acta Met.*, 1959, **7**, July, 469–477) The energy involved in the locking of dislocations by the Snoek effect and the liberating stress have been calculated for a screw dislocation in α-iron. It is suggested that the frictional force produced by the Snoek effect when a dislocation moves determines the flow stress of α-iron.

On the determination of the free enthalpy of mixtures of some ternary liquid alloys É. Bonnier and R. Caboz (*Compt. Rend.*, 1960, **250**, Jan. 18, 527–529) The calculations are applied to the Fe–Mn–Si system and compared with earlier values.

The equilibrium of silicon and oxygen in liquid iron M. G. Frohberg (*Stahl Eisen*, 1960, **80**, March 3, 299–301) This is a review of recent publications on the Si–O system in liquid iron, dealing in particular with the activities of Si and O at various temp. and with the [Si] [O] product.—T.G.

Silicon–oxygen equilibrium in liquid iron T. Kuwana (*Tetsu to Hagane*, 1959, **45**, March, 229–232) Thermodynamic data are given for the H_2–H_2O/Si equilibrium, activity coeff. of Si, effect of Si on the activity coeff. of O_2, etc.

Activity of carbon in liquid iron alloys. II. Effects of chromium, copper, niobium, sulphur, tin, and vanadium on the activity of carbon in liquid iron T. Fuwa and J. Chipman (*Tetsu to Hagane*, 1959, **45**, July, 681–689) Studies were made on equilibria with CO–CO_2 mixtures and the solubility of graphite in the melt. The relationship between the activity of carbon and alloying elements, j, is: $\epsilon_c^{(j)} = (\delta \ln f_c/\delta N_j)N_c$ values of $\epsilon_c^{(j)}$ are: S 12·0, Cu 4·2, Sn 0, Cr −5·1, V −8·0, Nb −23·0 in saturated carbon solns., V −6·1, Nb −11·5 (16 refs).—K.E.J.

Activity of carbon in liquid iron alloys T. Fuwa and J. Chipman (*Trans. Met. Soc. AIME*, 1959, **215**, Aug., 708–716) The effects of various elements on the activity coefficient of carbon in liquid iron have been studied by two experimental methods. The coefficient is increased by Al, Co, Cu, Ni, P, Si, S, and Sn, and is decreased by Cr, Nb, Mn, Mo, W, and V.—A.G.

Activity of carbon in iron–nickel alloys at 1000°C R. P. Smith (*Trans. Met. Soc., AIME*, 1960, **218**, Feb., 62–64) Ten alloys from the range pure Fe to pure Ni were equilibrated with four CO–CO_2 mixtures at 1000°C. A minimum solubility corresponding to maximum activity is observed which shows the lack of any adequate theory of metallic solutions.

The change of activity caused by addition of elements to liquid iron solutions near the carbon saturation point F. Neumann and H. Schenck (*Arch. Eisenh.*, 1959, **30**, Aug., 477–483) The limits of saturation of C in liquid iron and their displacement by added elements are discussed, and the relation between the reciprocal action of these elements and their positions in the periodic system examined. A method of calculation of C activity in liquid Fe–C alloys containing added elements is derived, together with graphical solutions.

Rate of dissolution of carbon in liquid iron H. Ebiko (*Tetsu to Hagane*, 1959, **45**, March, 220–221) Variations in thermodynamic data obtained with induction and resistance furnaces are discussed.—K.E.J.

Regarding the efficient assessment of the strength of cemented steel I. D. Rybasenko (*Chern. Metallurg.*, 1959, (2), 101–106) The strength of cemented steel is not determined only by the strength of the cemented layer but is conditioned by the nature of the stress system and depends also on the strength of the core. For working under compression the strength of the cemented layer must be higher as the hardness of the core is greater. For such types of loads as static tensile loads, bending, and uniaxial compression, the maximum strength is attained with an optimum carbon content in the layer. For dynamical bending and tri-axial unequal compression the effect of the carbon concentration is not noticeable.

Deformation structures of an 18–10 stainless steel B. Jaoul (*Rev. Mét.*, 1958, **55**, Oct., 976–992) Some abnormalities are pointed out by studying the tensile curves of austenitic stainless steels. Microscopy, X-rays, and mechanical properties show that two kinds of structure are developed by deformation: martensite below room temperature, the proportion depending on the magnitude of the stress applied and a bainitic type of structure above room temperature due to carbon diffusion (20 refs).—R.P.

Effect of applied tensile stress on phase transformations in steel L. F. Porter and P. C. Rosenthal (*Acta Met.*, 1959, **7**, July, 504–514) The transformation characteristics of a eutectoid steel have been studied under dead weight tensile loading by the simultaneous measurement of electrical resistance and extension of wire specimens. There is a threshold stress beyond which transformation is accelerated and plastic deformation was noted coincident with transformation. An hypothesis to explain these observations is advanced.—A.G.

Device for straining and fracturing thin foil specimens inside an electron microscope P. J. E. Forsyth and R. N. Wilson (*J. Sci. Instr.*, 1960, **37**, Jan., 37–38).

Contribution to the study of the propagation of Lüders bands in solid solutions J. Caisso and J. Micard (*Rev. Mét.*, 1960, **57**, Jan., 57–61) Examples given include mild steel, and the movement of Lüders bands during elongation is measured, oscillograph traces showing stress decreases. The results are discussed.

The effect of non-homogeneity of metals on deformation under tensile test W. Truszkowski (*Arch. Hutn.*, 1959, **4**, 283–322) The purpose of the paper is to establish a system whereby, as far as possible, the non-homogeneity of the metal can be determined from tensile test results. This was done as follows: First a theoretical course of deformation was established. This was in the form of an empirical stress-strain formula the coefficients of which have a physical meaning. If now a test is carried out, departures in the results obtained from those predicted should indicate non-homogeneity. Experiments on samples of non-ferrous metals showed the system to be satisfactory. It was found that departure from the predicted result was caused by impurities at the grain boundaries, coarsening of the grain structure and to a lesser extent by impurities inside the grain.

Effect of heat treatment on the mechanical properties of structural steels at low temperature I. E. Kontorovich and B. M. Voshedchenko (*Izvest. VUZ Chernaya Met.*, 1959, (7), 79–86) With a reduction in temp. a regular increase in yield-point and UTS is noticed, depending little on thermal treatment. The true impact breaking strength increases right up to the initial temp. interval of brittleness, below 0°. The maximum impact breaking strength is found in quenched steels tempered at low heat at −100° [330–345 kg/mm²]. The increase in this impact breaking strength depends on the chemical composition of the steel and on its thermal treatment.

Bend test for hardened tool steels (*Met. Treatment*, 1959, **26**, Dec., 473) The BISRA four-point loading bend test for measuring mechanical properties of tool steels is briefly described.—A.D.H.

Plastic torsion of iron whiskers at 300–20°K R. Conte, B. Dreyfus, and L. Weil (*Compt. Rend.*, 1960, **250**, Jan. 11, 337–339) Relaxation processes not observed in bulk metal are described.

Rupture testing of tubular specimens under internal pressure by hydrogen and at high temperatures N. N. Kolgatin, L. A. Glikman, and V. P. Teodorovich (*Zavods. Lab.*, 1957, **23**, (9), 1098–1101) Apparatus for the tests is des-

cribed and comparisons with tests using N_2 are made. Steels with 0·2%C, NM 1, and 17–8Ti (1Kh18N9T) were tested at 400, 450, and 500°C and up to 1000–1200 kg/cm². The effects vary from steel to steel.

Compressive strength of stainless-steel sandwiches at elevated temperatures E. E. Mathauser and R. A. Pride (*NASA–M–6–2–59L*, 1959, June, pp.50; from *Nucl. Sci. Abs.*, 1959, **13,** Sept. 15, 2061) Tests from 80–1200°F were carried out.

The effect of speed of impact in impact testing applied to grey cast iron A. de Sy and F. Deknock (*Fond. Belge*, 1960, **30,** Jan., 8–12) Various types of cast iron are tested.

Effect of specimen geometry on Charpy low-blow transition temperatures G. M. Orner (*Weld. J.*, 1959, **38,** Aug., 315s–323s) Low-blow Charpy tests were made on three types of steel. In the case of tests below the ductile–brittle transition temp., where the low-energy blow was sufficient to cause fracture, it was found that the low-blow test could be carried out at room temp. without affecting the temperature at which low-blow transition occurs. The Charpy low-blow transition temp. was found to be independent of notch and specimen geometry.

The chemical composition and heat treatment of steels used in the production of railway twin-wheels and axles to the specifications of the International Railway Union (UIC) V. Šmíd (*Hutník*, 1959, **9,** (10), 337–341) A statistical analysis of the effects of composition and production technology on the impact strength of railway axles resulted in the introduction of stricter limits on S and P contents, and in modifications in the process of manufacture. The improvements in mechanical properties now render the steel acceptable to the UIC.

Determination of transition temperature by notched tensile test bars and by miniature V-notched impact test bars C. Pfeiffer (*Jernkont. Ann.*, 1959, **143,** (11), 767–786) Tests carried out on ship plate showed that static testing with a very sharp notch was a good guide to transition temperature. Good correlation was obtained between impact tests with miniature bars and the Charpy test, provided that the geometry of the area tested is the same. However, when miniature bars are used for radiation ageing, for example, the lowering of the high energy absorption value by diminishing the test area can give results with the small bars which are up to 50% lower than with the Charpy V-test.

Ballistic evaluation of nickel steel plate at low temperature C. W. Amos (*WAL–TR–711–2/1*, 1959, July, pp.14; from *Nucl. Sci. Abs.*, 1959, **13,** Oct. 31, 2434) Two $\frac{3}{4}$ in. thick 9%Ni steel alloy plates that conformed to ASTM A353 alloy steel were subjected to a ballistic shock impact test at −165°C. The steel showed better properties than standard steel armour and low-alloy high strength structural steels.

Influence of ferrite and sigma phase on the properties of austenitic chromium–nickel steels, especially the aircraft material LW1670 H. Tauscher and H. Buchholz (*Neue Hütte*, 1959, **4,** Dec., 716–725) Two Ni–Cr Ti-stabilized austenitic LW 1670 steels, containing respectively 3 and 6% ferrite were investigated. It was shown that the 6% ferrite steel had a substantially lower impact strength after annealing at 700°C, and the same steel showed an accelerated formation of σ-phase from ferrite in tensile stressing. In general it was considered inadvisable greatly to exceed a 3% ferrite content in these steels (24 refs).

Celluloid replicas aid study of metal fractures K. Kornfeld (*Met. Prog.*, 1960, **77,** Jan., 131–132) For use in macrofractography, replicas of fractures were made from a solution of cellulose nitrate in methyl acetate, which bonds the fracture to a celluloid strip which can then be peeled from the specimen. Details of the technique are given.

Cold working and recovery textures E. G. Ramachandran and K. D. Maji (*TISCO*, 1959, **6,** Oct., 272–279) The qualitative and quantitative assessment of preferred orientations due to cold working and annealing are considered.

Transient phenomena arising from a sudden temperature change during plastic deformation of hot steel C. Rossard and P. Blain (*Compt. Rend.*, 1960, **250,** Jan. 18, 533–535) The changes are shown to resemble those observed at constant temperature on sudden changes of rate of traction.

Influence of the properties of crystals on the strength of metals in the hardened condition V. M. Karbonskii, G. U. Kurdyumov, and M. D. Perkas (*Fiz. Met. Metallov.*, 1959, (5), 752–756) The findings show that the increment in hardness because of cold deformation is not related to the magnitude of the distortion of the second order occurring during deformation, because it does not depend on the concentration of silicon. On the other hand, the deformation of the microvolumes increases proportionally to the hardness of the tempered material. The distortions of the second order by themselves cannot therefore be of great importance in cold deformation or in the martensite transformation but represent the properties of the crystals of the respective materials as regards the 'limit' of elastic deformation.

Electron-microscope observations on the work-hardening of high manganese steels: Addendum Z. Nishiyama, K. Shimizu, and T. Hiromoto (*Nippon Kinzoku*, 1959, **23,** Feb., 135–136) The width of strain markings found in cold-worked high-Mn steel increases with the progress of etching. This confirms the suggestion made in the previous paper (1958, **22,** 532) that the strain markings originated from a very thin layer which is probably of ϵ-phase.—T.G.

Tensile fatigue machine for testing wires and single crystals R. A. Dodd (*Rev. Sci. Inst.*, 1960, **31,** Jan., 69–70) Apparatus is described.

An introduction to the problem of metal fatigue G. M. Astles (*Metro-Vic. Gaz.*, 1959, **30,** Oct., 263–269) Methods of testing and factors affecting fatigue strength are discussed and basic theories are briefly outlined. An historical introduction is given and notes on designing to avoid fatigue.

A model of metal fatigue A. N. May (*Nature*, 1960, **185,** Jan. 30, 303–304) Calculations of the rate of crack formation are reported and rough numerical estimates are given.

A concept of fatigue damage J. I. Bluhm (*WAL–TR–893/202*, 1958, June, pp.20; from *Nucl. Sci. Abs.*, 1959, **13,** Aug. 15, 1819) A quantitative damage concept is derived from a simple model based on absolute strain in excess of current endurance limit. The criterion based on plastic strain is shown to fail for low stress level where plastic flow occurs.

Contribution to the study of high-temperature fatigue of metals J. de Fouquet (*Rev. Mét.*, 1959, **55,** Dec., 1133–1144) Alternate-torsion fatigue tests carried out between 20 and 700°C on mild steel containing 0·05%C have shown activation, due to reversed deformation, of crystalline structural modifications of the metal which can be set up by cold work and annealing. Three stages are detected. The influence of temp. on the crystalline behaviour of a metal subjected to fatigue is shown by micrographs, X-rays, and by changes in mechanical properties.—R.P.

An investigation of fatigue phenomena in metals by means of a recrystallization technique J. L. Peterson and N. H. Polakowski (*AFOSR-TR-59–91, Techn. Rep. No.*1; from *Nucl. Sci. Abs.*, 1959, **13,** Dec. 15, 2833) The effect of combined static cold working and fatigue on the recrystallization behaviour of several polycrystalline metals as shown by the annealed grain size was investigated. The most pronounced changes were observed in annealed metals, particularly low-C steel. An hypothesis is advanced to account for the different effects of softening, observed under cyclic stressing, on mechanical properties on the one hand and recrystallization capacity on the other.

Fatigue tests on parent metals and butt welds A. Kollmar (*Der Stahlbau*, 1956, **25,** Sept., 205–210) Comparative tests with St 37 and St 52 parent metals and a normal and a special quality butt weld showed the latter to give improved fatigue properties compared with the normal type of butt weld (27 refs).

Modified Goodman diagrams simplify the analysis of fatigue strength L. S. Clock (*Mach. Design*, 1959, **31,** Oct. 15, 167–169) A modification of the diagram using an experimental value instead of the $S_e/S_{UR} = 1/3$ ratio is described with examples.

Fatigue strength of electroslag welded joints in large steel castings I. V. Kudryavtsev and N. E. Naumechenkov (*Svar. Proizv.*, 1959, (1), 4–9) The welded joints of 35L steel with electroslag welding on specimens of 200 mm dia. (with and without heat treatment) have an ultimate resistance to wear not lower than that of the original metal (7·5–11 kg/mm²). The fatigue strength of cast 35L steel is appreciably lower than that of 22 K rolled steel.

Direct stress machine for combined fatigue and creep testing A. H. Meleka (*J. Sci. Instr.*, 1959, **36,** Nov., 468–471) A modified commercial machine is described.

The influence of internal stresses on the fatigue limit of materials of construction O. Ižďinský (*Zváranie*, 1959, **8,** (11), 328–336) [In Slovak] The effect of internal stress on the fatigue limit was studied in a series of specimens of mild steel of various thicknesses, containing welds. Internal stresses lowered the fatigue limit significantly in thick, but not in thin, sheet. Methods available for reducing the influence of internal stresses on the fatigue limit are discussed.—P.F.

Australian work on aircraft fatigue and life evaluation F. H. Hooke and P. S. Langford (*Aircraft Eng.*, 1956, **28,** Dec., 408–414).

The effect of metallurgical variables on the fatigue properties of AISI 4340 steel heat-treated in the tensile strength range 260,000–310,000 p.s.i. J. I. Fisher and J. P. Sheehan (*WADC Techn. Rep.* 58–289; *ASTIA Doc.* 208321; *PB* 151661, 1959, Feb., pp.144) Eight heats of AISI 4340 (a low-alloy, medium C, Ni–Cr–Mo steel) were produced so as to obtain a variety of nonmetallic inclusions, and fatigue properties were examined by the rotating beam method at the 260000–310000 lb/sq.in. level. A fairly good correlation was found between the mean width of the largest inclusions and the ratio of endurance limit to tensile strength, i.e. the less the inclusion size the greater the ratio. No effect on fatigue properties was observed when amounts of retained austenite and dissolved H_2 and N_2 were reduced.

The role of the frequency of loading in resistance Yu. S. Danilov and N. V. Kadobnova (*Zavods. Lab.*, 1959, (6), 727–731) The strength of metal under alternating loading depends on the time of action of the stress and on its frequency. When reducing the frequency from 4750 to 7·6 cycles per min, i.e. by a factor of 630, the duration of the test for all materials investigated increased between 100 and 500 times while the resistance to the number of cycles decreased by a factor of 1·5 to 5. The zones of fatigue failure do not depend on the frequency of loading.

The determination of the influence of fatigue on TOR steel S. Soretz (*Österreich. Ing. Z.*, 1959, **2,** Sept., 325–327) Results of pulsating tensile stresses on TOR steels for reinforced concrete are reported, and related to the strength requirements for these steels.

A theory for the effect of mean stress on fatigue of metals under combined torsion and axial load or loading W. N. Findley (*ASME Trans. J. Eng. Ind.*, 1959, **81B,** Nov., 301–306) A rational theory for the influence of mean stress superimposed on the alternating shearing stress in a cycle of fatigue is propounded, consistent with the known trends of fatigue data for ductile metals and cast irons.—S.H.–S.

The testing of wire ropes E. A. Franke (*Draht*, 1960, **11,** Feb., 56–59) The author stresses that in the testing of wire ropes not only the finished ropes but also the individual wires should be tested. From his experience he devised a number of testing machines for both ropes and wires. All together, five machines are described and illustrated in which the samples can be subjected to bending fatigue, alternating bending fatigue, tension, and vibration and, if required, wear. The peculiarities of the individual machines are briefly mentioned. These machines allow the properties of wire and rope to be determined in a fraction of time hitherto taken.—T.G.

An analysis of critical stresses and mode of failure of a wire rope W. L. Starkey and H. A. Cress (*ASME Trans. J. Eng. Ind.*, 1959, **81B,** Nov., 307–316) A paper proving by mathematical analysis that by far the greatest stress in a wire rope results from Hertz contact

stresses at points of contact of wire-on-wire, and maintaining that fretting fatigue initiated at such points of contact is the usual mode of failure. Design relationships based on these concepts, as opposed to the theory that the significant stress is the tensile stress, are postulated.—S.R.–S.

Distribution of fatigue cracks in specimens of ship-building steels G. N. Usevolodov (*Zavods. Lab.*, 1959, (6), 734–735) The distribution of fatigue cracks in steel sheet was investigated under repeated-alternating bending cycles with different stress concentrations and specimen dimensions. Graphs have been constructed from experimental results between the limiting loads and resistance.

Analysis of fatigue fractures of quenched instrumental steels R. S. Nikolaev and I. E. Kolosov (*Zavods. Lab.*, 1959, (8), 990–991) The investigations have shown that in the majority of cases the initial fatigue cracks are of a circular form radiating from a point. This is easily visible in the MBS–2 microscope, but produces the impression of brittle fractures when seen with the naked eye. These zones are wrongly taken as flakes which of course results in a false explanation of the causes of failure. It is an undoubted fact that these steels fracture brittle, even with small initial fatigue cracks, due to the great tendency of these steels quenched to a higher hardness ($R_c = 60$) to the formation of cracks.

The causes of the appearance of fatigue lines on fractures Ya. B. Fridman and A. M. Zaitsev (*Zavods. Lab.*, 1959, (8), 992–995) Flat discs and T-shaped specimens of various steels with an impact breaking strength between 100 and 140 kg/mm² were tested under constant conditions regarding direction, periodicity, and magnitude of loads; with regular changes in periodicity and in the tensile loads, and with irregular changes. Results have shown that fatigue lines form with short-time loadings simulating the starting moments of machines; these lines appear at the boundaries of zones of different coarseness.

New machine for measuring fatigue under alternating bending stresses at elevated temperatures under vacuum or a controlled atmosphere J. de Fouquet, R. Jacquesson, and P. Laurent (*Rec. Mét.*, 1960, **57,** Jan., 62–66) In the machine described, alternating bend fatigue can be measured at up to 1000°C under a vacuum or in a controlled atmosphere, at 10–50 cps.

On the fatigue strength of a copper coating sprayed on steel bars J. Salokangas and P. Lehto (*Acta. Polytech. Scand.*, 1959, *ME* 6, *Mech. Eng. Series No.*6, pp.20) [In English] Fatigue cracks were observed and their incidence related to wire feed and spraying distance. The stress sustained for 10^7 cycles, without producing a crack was defined as the fatigue strength of the sprayed coating.

On the relation between the thickness of decarburizing layers and the fatigue strength of carbon steels R. Inoue and S. Tsujimoto (*Sumi. Met.*, 1959, **11,** July, 181–186) Investigations were made on 0·39% and 0·60%C steels. With stress concentration factors of 1, 1·37, and 2·11, fatigue strength decreases markedly and the thickness of the decarburized layer has a minor effect. Near 3·02, the notch sensitivity becomes more important than the thickness of the decarburized layer.

Fatigue failures considered particularly from the point of view of their characteristics G. A. Cottell (*PACT*, 1959, **30,** Oct., 409–413) The effects of surface state and corrosion on fatigue failure are discussed together with the micromechanism of this type of failure.—A.G.

Service life of machine components under varying loads and the summation of the fatigue S. A. Shuvalov (*Vestnik. Mashin.*, 1959, (5), 3–9) The results given refer to contact stresses. In the calculations for components operating with changing load amplitudes, the problem of load and permissible stresses has to be solved. A method of calculation is given which can be applied to different conditions and equations are given for summating fatigue.

Studies on 12% chromium heat-resisting steels XII: Creep rupture properties of H46 and TAF steel T. Fujita (*Tetsu to Hagane*, 1959, **45,** March, 362–364).—K.E.J.

Influence of crystallographic order on creep of iron–aluminium solid solutions A. Lawley, J. A. Coll, and R. W. Cahn (*Trans. Met. Soc. AIME*, 1960, **218,** Feb., 166–176) Creep curves for solid solutions with up to 28 at.%Al at temp. order-disorder transformation have been traced. Creep resistance appears to be determined by state of order. Initially the alloys show accelerating transient creep, sometimes intermittent negative creep.

Regularities in creep and hot fatigue data. Part II K. F. A. Walles and A. Graham (*ARC–CP*–380, 1956, Dec., pp.140; from *Nucl. Sci. Abs.*, 1959, **13,** Sept. 30, 2173) The theory is examined for 103 sets of published data for 44 compositions, alloys of Fe, Ni, Cr, and Co. The extent of agreement is assessed.

Grain growth and creep in metals K. A. Osipov (*Doklady AN*, 1959, **128,** (3), 529–531) It has been proved by the author that the maximum energy at the grain boundaries is obtained for metals with face and body centred lattices, with large angles of disorientation. In the presence in the metal of widely unoriented crystals, the limiting energy for softening the activation condition, both for grain growth and for irregular creep can be brought about by purely geometrical means, i.e. disorientation of the crystals. Any additional heat fluctuation of the activating energy is not necessary in such cases.

Creep deformation in a single riveted structural joint under axial tension. Task title: Fatigue and creep of materials J. Marin (*WADC–TR*–57–757, *AD*–216712; 1957, March–Dec., pp.12; from *Nucl. Sci. Abs.*, 1959, **13,** Dec. 15, 2841–2842) After reviewing the literature, and showing that attempts to determine the creep of riveted joints have been mainly confined to overall creep in various types of joints, a procedure for predicting theoretically the creep deformation of a simple riveted joint is outlined, creep of the component parts of the joint being considered.

Furnaces for creep testing H. Banneitz (*Z. Metallk.*, 1960, **51,** Feb., 131–132) The fundamental requirements on furnaces for creep tests are temp. constancy over periods up to 10^5 h, even temp. distribution and even and constant stressing during this time. An electric furnace is described that will fulfil those requirements up to 750°C. The test piece is spring-loaded. A block diagram is appended.

The strengthening of austenitic solid solutions F. Eberle, J. H. Hoke, E. J. Rozic, and W. E. Leyda (*WADC Tech. Rep.* 58–28; *ASTIA Doc.*, 151161; *PB* 131992, 1958, April, pp.60) The room temp. mechanical properties and creep-rupture strengths at 1600 and 1800°F are determined on a range of C-free Fe–Cr–Ni, Cr–Ni, Fe–Cr–Co alloys, the investigation being concentrated on Co and Ni base alloys. In the second part of the investigation three methods of raising creep-rupture strength were used—solid solution hardening, complex-carbide hardening, and dispersion hardening by the addition of intermetallic compound formers.

Measuring accuracy in creep tests. Part I. Influence of eccentricity of load A. Mellgren (*WADC–TR*–59–78 (*PA* 1); *AD*–216357; 1959, Feb., pp.27; from *Nucl. Sci. Abs.*, 1959, **13,** Nov. 15, 2584) The influence of eccentricity of loading on the result of creep tests was investigated. The effects of curved test specimens, asymmetric location of extensometers, inhomogeneous materials, and non-uniform cross-sections were studied and mathematical formulae applied.—D.L.C.P.

Structural changes of austenitic chromium nickel steel during creep tests for several years W. Koch, A. Schrader, A. Krisch, and H. Rohde (*Forsch. Wirts. Nordrein–Westfalen, No.*680, 1959, pp.37) Four austenitic Cr–Ni steels, two of which were Ti- and the other two Nb-stabilized were creep-tested between 600 and 700°C for up to 50000 h. The carbides and intermetallic compounds of the steels were isolated and examined. It was found, *inter alia*, that in tests of a shorter duration only monocarbides were present, but this changed with increasing time to $Me_{23}C_6$ which, however, later disappeared forming a σ-phase compound. The course of this structural change depended on the temperature and the load. All four steels showed the same reaction sequence although their velocity was different.

Choosing metals and alloys for creep resistance M. G. Gemmill (*Eng. Mat. Design.*, 1959, **2,** Nov., 545–548) Steel types and Ni alloys and their uses in gas turbines, superheaters, and other power plant are reviewed.

Study on AISI 321 type stainless steel for steel tube used at elevated temperature. I. Creep-rupture strength of stainless steel containing ferrite K. Yoshida. **II. Creep-rupture strength of austenitic stainless steel** H. Hirano (*Tetsu to Hagane*, 1959, **45,** March, 380–381; 381–383).—K.E.J.

Research and failures of metals in service C. E. Phillips and A. C. Low (*Trans. Inst. Marine Eng.*, 1959, **71,** Dec., 357–365) Work at the National Engineering Laboratory is described. The examination of failures in service, size effect, and fatigue strength reduction factors, fretting, corrosion fatigue, and failure at high temperatures are considered (17 refs).

Failure in a shaft A. Taub (*Met. Prog.*, 1960, **77,** Jan., 109–110) Investigation of the failure of a machine tool shaft to specification En 9, heat-treated at one end by quenching and tempering, showed failure to be due to defective heat treatment, as undesirable growth of carbide particles associated with bainite, and leading to diminished fatigue strength, was found near the quenched end.

Contribution to the accuracy of the Vickers hardness measurement under various loads A. von den Steinen and W. Schmidt (*Arch. Eisenhütt.*, 1960, **31,** Jan., 25–32) The Vickers hardness is independent of the load as long as the load is high (Kick's law), and is expressed by $p = a.d^2$, where p is the load, d the diagonal of the indentation, and a a constant. If the load is small—and there is a tendency in industry to use smaller loads with smaller machines apart from the micro-hardness measurement—then $p = a.a^n$, where n varies between 1·7 and 1·9 (Meyer's law), but it seems that n is not constant for one and the same material as it shifts to lower values with lower loads. It is recommended that when employing small loads the number of measurements should be increased in order to eliminate the uncertainties inherent in these measurements.—T.G.

Problems of hardness testing of thin sheet metals E. D. Bergsman (*Annual Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 7–16; 20) The preparation and mounting of specimens, the choice of indenter, load, speed of loading and contact period, the measurement of impressions, the dependence of hardness number on load, the significance of micro-testing, and the advantages and disadvantages of the Brinell, Rockwell, and Vickers methods are considered. A nomogram due to G. Segerud, that shows the maximum permissible load to be used for testing strip of known thickness (in the range 0·01–2·5 mm) and where an estimate of the hardness can be made beforehand, is presented, and examples of its use are given.

Scratch hardness measurement with a diamond pyramid T. Land and B. Sugarman (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 17–20) The authors first used imperfect diamond indenters, and it was found that the scratch width was not strictly proportional to (load)$^{\frac{1}{2}}$. On using 'perfect' indenters the proportionality was very close. The relation of scratch hardness to indentation hardness appeared to vary with different materials.

Possible sources of error in hardness testing K. Meyer (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 21–31) The author analyses the Rockwell, Vickers, and Brinell methods, and shows all the factors liable to cause errors.

Experiences with the double-cone indenter P. Grodzinski (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 39–46) The theoretical and practical advantages of the double-cone indenter are considered, and some examples of its use are given.

The physical meaning of indentation hardness D. Tabor (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 417–455) The author considers the elastic and plastic properties of metals, the hardness of ideal

plastic metals, the hardness of work-hardening metals, the Meyer law, the relationship between hardness and UTS, elastic recovery, and the meaning of indentation hardness.

Practical application of the Reichert micro-hardness tester E. M. Ornitsch-Modl (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **8,** 61–64) The Reichert micro-hardness tester is described, and typical examples of its use are given. It is mentioned that, although the macro-hardness of cold worked metals increases with the percentage of cold-work, it has been found that the micro-hardness remains almost constant, irrespective of cold work.

Rockwell hardness testing of sheet materials V. E. Lysaght (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 65–71) The use of the Rockwell hardness tester for quality control of sheet and strip ferrous and non-ferrous metals is discussed, with particular stress laid on the advantages of the tester.

Hardness testing with the Vickers machine H. G. Harper (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 77–83) The development, construction, and use of the Vickers hardness tester are described, and stacking of thin sheets and impressions in brittle materials are considered in some detail.

Reproducibility of hardness tests J. Woolman (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 84–89; 101) The expected errors in Vickers and Brinell hardness testing methods are discussed, and the results of practical tests on sheet and block specimens are then considered. Three machines of each type, three operators, and three measuring instruments were used in each case, and the errors arising from each source were analysed.

The value of hardness testing as an inspection procedure W. G. Shilling (*Ann. Proc. Sheet Strip Met. Users' Techn. Assoc.*, 1953, **6,** 90–94) The Brinell, Vickers, and Rockwell hardness testing methods are considered as applied in inspection. The effect of individual errors, and the use of statistical methods, are discussed.

Hardness of cast martensite in terms of its carbon content G. Aubrion (*Fonderie*, 1959, June, 266–271) A study of two theories on the hardness of castings: (a) the role of graphite flakes and the phosphide eutectic: (b) the influence of maintenance at austenitizing temp. before hardening.—S. H.–S.

On the standardization of hardenability of steel. I. The hardenability distribution of JIS SCM4 and its hardenability band. II. Factors controlling the hardenability of steel E. Tsuya (*Nippon Kinzoku*, 1959, **22,** Sept., 472–476, 477–480) I. The hardenability band agrees with that for AISI 4140 H. Calculated Jominy bands are not suitable for establishing hardenability bands. II. The hardenability of Cr–Mo steel may be correlated with melting conditions, austenitic grain size, and Mo content, and to a lesser degree with the contents of C, Cr, Mn, Cu, and Si.—K.E.J.

Eccentric hardenability test for shallow hardening steel. II. Effect of chemical composition on the hardenability of carbon steel T. Suzuki (*Tetsu to Hagane*, 1959, **45,** March, 330–332) Comparisons are made between Jominy and eccentric bars and tests, and results are given for the hardenability of boron-treated steels.—K.E.J.

On the difference between electropolished and mechanically polished surfaces of some steels in micro-Vickers hardness Y. Masuko (*Tetsu to Hagane*, 1959, **45,** March 303–304).—K.E.J.

Anisotropy of the hardness and shape of indentations V. K. Grigorovich (*Zavods. Lab.*, 1959, (5), 601–605) The anisotropy of pyramidal indentations must be observed in the non-uniformity of the sizes of the indentations on the differently oriented surfaces, in the differences between the diagonals of the same indentation and in the different curvatures of the various sides of the indentations. From a theoretical consideration of these non-uniformities formulae are derived and results so obtained are compared with the experimental findings.

Study on the standardisation of hardenability of steel (*Rep. Gov. Mech. Lab.*, 1959, (29), pp.24) [In Japanese].—K.E.J.

Static and dynamic measurement of the hot-hardness of iron alloys at temperatures up to 1000°C H. Schenck, E. Schmidtmann, K. Mauer, and H. Brandis (*Arch. Eisenhüt.*, 1960, **31,** Jan., 33–38) The authors describe an improved version of their small-load hot-hardness tester which was employed in their measurement of the hot-hardness of a number of iron alloys. At the same time, dynamic measurements were carried out with an apparatus that is described. The effect of the various alloying elements can clearly be seen from diagrams. The results of the dynamic and static measurements show excellent agreement.—T.G.

The effect of phosphorus on ageing after cold working of basic Bessemer steel F. Erdmann-Jesnitzer (*Hutnik*, 1959, **26,** (10), 401–407) Increase in P content retards the ageing process whereas the tendency to ageing increases considerably with N-content.

Intermetallic reactions and ageing effect in thin films C. Weaver and R. M. Hill (*Advances in Phys.*, 1959, **8,** Oct., 375–437) Notes on Fe–In, Fe–Ni, Fe–Sn, and Fe–Zn thin films prepared by evaporation are included among many non-ferrous systems.

High temperature ageing structures in γ' hardened austenitic alloys W. C. Hagel and H. J. Beattie, jun. (*Trans. Met. Soc. AIME*, 1959, **215,** Dec., 967–976) Variations in the secondary-phase reactions of nickel- and cobalt-base alloys were determined as a function of solution treatment between 1700 and 2200°F and ageing between 1200 and 1800°F. Precipitation hardening of these alloys results mainly from the grain-interior formation of γ'; $M_{23}C_3$ appears principally as grain-boundary cells which can be eliminated by intermediate high-temp. ageing treatment (17 refs).—T.G.

The influence of the long term ageing of the austenite weld metal on its tendency to intercrystalline corrosion M. A. Gal'perin and V. V. Ardentov (*Avtom. Svarka*, 1959, (1), 36–42) The tendency of the weld metal to intercrystalline corrosion as a function of temp. and long-term ageing is best tested with bending. If the weldment is used at high temp. (1Kh 18N9T steel) the test must be carried out according to GOST (6032–51) and also after a long period of exposure to the high temp. It has been shown experimentally that the loss of resistance of the metal to intercrystalline corrosion is due to the appreciable change in the composition of the carbide phase, especially to the increase in the Cr content.

Mechanism of brittle fracture J. Plateau (*Bull. Cercle d'Etudes Met.*, 1959, **7,** Dec., 523–540) Modes of fracture are classified, illustrated and discussed, and the various mechanisms advanced are reviewed. Mild steel in tension is used and the relation to Lüders bands is considered.

A new method to test steel for temper brittleness A.–F. K. Kaddou and P. C. Rosenthal (*Trans. Met. Soc. AIME*, 1960, **218,** Feb., 189–190) An internal friction method was used on wires 0·064 in. dia.×6 in. long. The wire-wrap bend method was used and a device was constructed. The curves resemble Charpy impact curves but still show an effect above the transition temp. not shown on impact.

On the conditions governing the brittle fracture of iron single crystals H. K. Birnbaum (*Acta. Met.*, 1959, **7,** July, 516–517) A letter. Recent investigations show that under tension iron single crystals may show either ductile or brittle behaviour depending on orientation purity and temp. The hypothesis that mechanical twin boundaries provide the barriers causing dislocation pile up and cleavage is shown to be consistent with the observed facts.—A.G.

Stress behaviour of brittle materials E. B. Shand (*Ceram. Bull.*, 1959, **38,** Nov., 653–660) Steels are included. Mechanisms of fracture and the significance of impact testing are also considered.

Embrittlement of ultra-high tensile steels in relation to surface coatings R. L. Samuel and N. A. Lockington (*Trans. Inst. Met. Fin.*, 1959, **36,** (4), 135–141) The delayed fracture of notched tensometer tensile test-pieces of hardened and tempered steel containing 0·4%C, 1·5%Si, 1·5%Mn, 1·75%Ni, 0·4%Mo, and 0·4%V coated with Zn, Cd, Al, Ni, Ni+Cr, and silicone lacquer respectively were studied at a constant load of 70–90% of the breaking load in the normal atmosphere and in a 3%NaCl spray. In the absence of corrosion Cd plated specimens fail in 1–100 h at a load of 80% if the fracture stress whereas Zn-vapour coated and Ni plated specimens are insensitive to delayed fracture. In corrosive environments rapid failure took place of coated and uncoated specimens. The failure is related to the mechanism of corrosion rather than to its extent.

Study of the cold brittleness of plain carbon steel. III. Fracture characteristics in the tensile test S. Nakanishi (*Tetsu to Hagane*, 1959, **45,** March, 319–320) The relationships between physical properties and the angle between the tensile axis and rolling direction are shown graphically.—K.E.J.

The morphology of brittle fracture in pearlite, bainite and martensite A. M. Turkalo (*Trans. Met. Soc. AIME*, 1960, **218,** Feb., 24–30) A steel with 0·55%C, 1·3%Mn was examined at −196°C with the electron microscope. Fracture facet size was larger with pearlite and upper bainite than with lower bainite and martensite. The most resistant type of martensite showed the finest fracture. Decrease of structural unit size might increase toughness further.

Hydrogen embrittlement of steel by cathode charging, pickling and cadmium plating K. Sachs and S. H. Melbourne (*Trans. Inst. Met. Fin.*, 1959, **36,** (4), 142–152) The effects of electrolytic cathodic charging followed by ageing and of plating processes variables on the hydrogen embrittlement of mild steel screws and 0·7%C spring wire were studied using bend tests as a measure of ductility. The results showed considerable scatter and the relative severity of embrittlement induced by the process depends on the components to be plated.—A.D.H.

Influence of mode of fracture on the classification of steels by conventional criteria of brittleness H. Herbiet and P.–E. Lagasse (*Rev. Mét.*, 1959, **56,** Dec., 387–393) With particular reference to the determination of weldability, especially the position of the ductile-brittle transition temperature, a series of comparative tests using different types of brittleness test were made on 10 low-C steels. The tests used included the V-notch impact test, and the Van der Veen, NRL drop weight, and the Robertson crack arrest tests.

Discontinuous crack growth in hydrogenated steel E. A. Steigerwald, F. W. Schaller, and A. R. Troiano (*Trans. Met. Soc., AIME*, 1959, **215,** Dec., 1048–1052) The kinetics of crack propagation in a hydrogenated high strength steel at subzero temp. indicated that cracking progressed in a discontinuous mode. The incubation time required for the initiation of delayed failure was controlled by the stress-induced diffusion of H_2. The activation energy for this process was 9120 cal/g-atom. At a temp. of −50° incubation and fracture times were coincident resulting in instantaneous, catastrophic fracture (16 refs).—T.G.

The brittleness of 13%Cr steels used for castings P. Fremunt and A. Lorenc (*Slévárenství*, 1960, **8,** (1), 5–8) Slow cooling of low carbon 13%Cr steels from the tempering temp. leads to embrittlement. The nature of the effect is not entirely clear. Several preliminary experiments with various heat treatments showed that the embrittlement may be combatted successfully.—P.F.

The effect of plastic deformation in the austenitic state on the kinetics of the development of temper brittleness in 30KhGSA steel E. N. Sokolkov (*Fiz. Met. Metallov.*, 1959, (3), 384–388) Results of numerous experiments have suggested an explanation of the reduction in brittleness when combining plastic deformation with quenching so as to exclude the recrystallization of the work-hardened layer. The conclusion is therefore that this reduction in brittleness is not due to a change in the kinetics of phase transformation but that the plastic deformation of steel in the austenite state causes a change in the crystal lattice in the intercrystalline zone and adjoining regions which produce the changes in the conditions and form of the phase transformation or combinations causing the appearance of brittleness.

On the nature of the 475 degree brittleness of the chromium–nickel stainless steels V. I. Dyatlov and N. I. Kopersak (*Avtom. Svarka*, 1959, (5), 66–82) Owing to the interphase redistribution over the entire volume of the ferrite phase, atomic complexes form, a proportion of which are enriched and a proportion depleted of Cr. This shows outwardly in a highly etchable ferrite phase with a 475° brittleness and in its coloration when etched with oxalic acid. There seems to be a close relation between the formation of the σ-phase at high temp. and the 475° brittleness so that the latter may be considered to represent the incubation period of the formation of the σ-phase.

The embrittlement of steel by absorption of atomic hydrogen O. Werner (*VDIZ*, 1959, **101**, Oct. 1, 1303–1304) The causes of H_2 absorption during steel manufacture and treatment and theories of the mechanism of H_2 embrittlement are briefly reviewed.

Wear research and rheology G. Salomon (*Materialprüfung*, 1959, **1**, Dec. 23, 385–390) The author defines the various types of wear and the kinetics involved in wear processes and then discusses the relation between volume properties, friction, and wear.—T.G.

Wear of carbon steel at high temperature and in a vacuum. III E. Miyoshi (*Nippon Kinzoku*, 1958, **22**, Dec., 644–648) At room temp., wear loss *in vacuo* is smaller than in air, but at high temp. the reverse applies. The hard layer (900–1000 micro-Vickers) is believed to reduce wear-loss. The load-wear loss curve shows one max. and one min., the former caused by thickening of the hard layer and the latter by rise of surface temp.—K.E.J.

Wear of steel at high temperature. IV. Hard layer on the frictional surface. V. Effects of oxygen on friction of steel E. Miyoshi (*Nippon Kinzoku*, 1959, **23**, Jan., 19–22; 23–26) IV. Tests on the very hard layer found on the surfaces of wear test-pieces in vacuum show that it consists of severely and repeatedly cold-worked powder; the particles were detached but become attached to the surface again. V. Tests in oxygen, nitrogen, and air show that wear is much affected by the partial pressure of oxygen but not nitrogen. The max. wear occurs at 0·1–1 mm Hg pressure, because the wear powder cannot become re-attached. Steels for hot-working tools should be chosen for heat-resistance and oxidation properties; a thin oxidized surface accelerates wear at high temp. **VI. Mechanism of wear in a vacuum** (Feb., 83–86) The relation between wear and hardness in short-time wear tests at high temp. was studied. For each temp. there is a critical hardness that characterizes wear. With increasing temp. the critical hardness decreases. It is concluded that the hardness is related to the separation of a powdery wear product from the rubbing surface and that the critical hardness depends on the relative hardness of the powder and the surface of the test piece.

Radioactive tracer method for determining gear wear S. Enomoto and K. Tsugawa (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1959, **8**, Sept., 643–648) An experiment is described lasting 10 min in which the wear of a gear was measured by combining a radioactive gear with a normal gear and measuring the radioactivity of the lubricant that was circulated through the gear box. Operating speed and load had an effect on the wear rate.—T.G.

The wear of gear teeth. IX. The mechanism of pitting (4) K. Ishida and T. Muta (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1959, **8**, Oct., 671–685) The mechanism of growth of the pitting cracks produced by a rolling-disc machine on the surface and the interior of C steel discs was analysed by optical microscopy, micro-hardness, and X-rays. The results are reported and supplemented by many diagrams, tables, and micrographs.—T.G.

The wear of gear teeth. X. The effect of hardness on pitting K. Ishida and T. Muta (*Rep. Gov. Ind. Res. Inst. Hagoya*, 1959, **8**, Nov., 753–767) Experiments were made on the effect of hardness and the depth of the hardened zone on the pitting of C steel under lubricated conditions in a rolling disc machine. Fully hardened specimens and normalized samples showed the same type of pitting. In induction-hardened specimens no cracks occurred if the hardened zone was more than 0·4 mm deep, when it was thinner, flaking was observed under high contact pressures. The harder the surface zone the lower were the pitting cracks. The results are presented in tables, graphs, and photographs.—T.G.

The geometrical aspect of erosion O. Bita (*Met. Const. Masini*, 1959, (12), 864–867) This study was carried out on bearings with hydrodynamic lubrication and conditions of operation, speed, temp, etc. have been considered in relation to abrasion, erosion, vibration, cavitation, etc. It is shown that the geometrical aspect of erosion helps to interpret the causes and facilitates their removal.

Assessing the effect of surface-active coating on the deformation surface during friction V. D. Evdokimov and A. S. Radchik (*Doklady AN*, 1959, **128**, (4), 713–741) The surface-active substances have a twofold action on the hardness of the surface, reducing or increasing it under certain conditions. The method used in these determinations, that of the friction on thin laminae, has high sensitivity.

Force of friction and surface deformation V. D. Evdokimov and A. S. Radchik (*Doklady AN*, 1959, **128**, (5), 921–923) The method consists of measuring deformation of the surface by means of a wire tensometer, the construction of which is given. Steel, bronze, cast iron, Al, and textolite were investigated. In most of the materials lubrication reduces deformation (absolute value) and the force of friction within the same layer of grease depends on the nature of the surfaces in contact. For non-greased surfaces the development of deformation with an increase in the force of friction is related to the moduli of elasticity.

Radioactive methods for the study of erosion and lubrication D. Pavelescu (*Met. Const. Mas.*, 1959, (10), 852–856) The principle of the method is the measurement of pulses given out by the radioactive particles which pass through erosion into the oil, one of the surfaces being first activated. The method is specially sensitive in dry friction when the radioactive metal can be traced as it passes from one surface to the other. The most usual isotopes are ^{60}Co, ^{51}Ti, ^{185}W, and ^{182}Ta of which ^{185}W is preferred since it emits β-radiation of average energy of 0·428 MeV with a half-life of 73·2 days.

On the possibilities of wear research and wear measurement of machine-tool parts offered by the use of radioisotopes H. Lachmann (*Technik*, 1960, **15**, Jan., 31–34) An introduction to the use of radioisotopes in wear research and measurement based on published information.—T.G.

Wear and damage of railway wagon wheels V. A. Kislik (*Vestnik. Mashin.*, 1959, (7), 59–64) The article considers both types of wheels, solidly cast and with tyres and is a survey of the views of various investigators on calculating fatigue and wear in order to predict the service life of both these types of wheels. Some conclusions are drawn. The steel for solid cast wheels must have an increased C content; the minimum UTS for wheels must be 85 kg/mm². The control of the macrostructure both of finished wheels and of blanks must be carried out.

Recent developments in wear-resistant cast materials for crushing hard minerals T. E. Norman and G. E. Ott (*Giesserei*, 1959, **46**, July 30, 441–447; Aug. 13, 471–478) The development, manufacture, and properties of ferrous materials for grinding mill parts are described, with reference to practice at the Climax Molybdenum Company, Colorado. Alloys described are: Mn steel with 12%Mn and 2%Mo, pearlitic, and martensitic Cr–Mo steels, and white irons containing 15%Cr and 3%Mo, and 3%Ni, 2%Cr, and 1%Mo respectively (7 refs).

Manufacture and maintenance of marine Diesel parts F. Danis (*Fonderie*, 1959, **160**, May, 209–220) Causes of wear arising from (a) the type of motor, (b) the character of usage, due to various forms of direct mechanical action, together with experimental results relative to cylinders and parts, are described. Metallurgical composition of castings and problems peculiar to moving parts are discussed.—S.H.–S.

Optical constants of a steel surface H. Morokuma, Y. Miyasita, and H. Hasunuma (*Oyo Butsuri*, 1957, **26**, (10), 536–538; *CEA-tr-X* 118, pp.17; trans. into French. From *US Dept. Commerce Techn. Trans.*, 1959, **2**, Nov. 20, 741) Mechanically and electrolytically polished samples were examined in a polarizing spectrometer.

Study of a proposed theoretical structural model to represent a very thin metal film P. Dumontet and J. P. David (*Compt. Rend.*, 1960, **250**, Jan. 18, 518–520) The transmission and reflection fields in a plane electromagnetic wave are derived.

The radiation property of metals in the liquid phase A. M. Samarin and D. Ya. Svet (*Doklady AN*, 1959, **126**, (1), 78–80) In *ibid*, 1956, **108**, (1) the method of modulation reflectometry was described by which the radiating property of the surface of a metallic bath in the visible and infra-red spectra can be determined from the reflection coefficient. This publication adduces experimental results for various metals.

Photoelasticity can help the designer J. R. Dixon (*Eng. Mat. Design*, 1959, **2**, Dec., 600–604) Typical photoelastic investigations of stress systems in relatively complicated systems are described.

Versatile photostress optical transducer Tatnall Measuring Systems Co. (*Eng. Mat. Design.*, 1959, **2**, Dec., 630) A note on a photostress gauge. On stressing, the colour fringes move a distance directly proportional to the strain.

The study by an optical method of the texture of transformer steel K. V. Grigorov and P. B. Izbranov (*Fiz. Met. Metallov.*, 1959, (4), 614–621) The type of the recrystallization structure of transformer steel depends on the degree of deformation. With a low degree of deformation (when the reduction of thickness in rolling is less than by a factor of 10) the texture of the first order is characterized by the orientations (100); [001]; (110); [001]. With a large degree of deformation texture of the second order predominates (100); [001] rotated to the normal of the rolling surface through an angle of 15–18° on either side.

Changes with time of the reflecting power of mechanically polished metals G. P. Skornyakov add K. A. Efremova (*Fiz. Met. Metallov.*, 1959, (3), 395–399) A joint electronic investigation and measurement of reflecting properties has shown that metals with a polished surface with high resistance to oxidation do not show with time any appreciable changes in structure and optical properties, but metals subject to oxidation show changes in reflecting properties. This is due to the formation of oxide layers. The similar angle of rotation of the plane of polarization in the Kerr effect for a mechanically or electrically polished surface, i.e. for two different structures and different reflecting properties may occur either because in strong magnetic fields the saturation is the same or because the difference is too small to be measured.

The importance and limitation of the inspection of materials with penetrants R. Labruyère (*PACT*, 1959, **30**, Oct., 404–408, 424) The various methods of inspection available are reviewed and factors limiting the accuracy of penetrant tests are discussed, considering the use of colourants and fluorescent material. The advantages and defects of penetrant inspection are finally assessed.—A.G.

The effect of crystal textures and other magnetic anisotropies on magnetic properties F. Assmus (*Schweiz. Arch. Wiss. Techn.*, 1959, **25**, Aug., 290–296) The various magnetic anisotropies which occur in ferromagnetic materials—crystal orientation and shape—are discussed in relation to their influence on magnetic properties, and a review is given of a number of soft and hard magnetic materials, with details of some as-cast and worked textures, fine powder effects, recrystallization textures, and other phenomena exhibiting anisotropy (26 refs).

Non-destructive testing by the magnetic powder technique H. J. Marschall (*Schweissen Schneiden*, 1960, **12**, Jan., 25–26) The author reviews the latest instruments for the non-destructive testing of fabricated parts. He deals briefly with the apparatus, indicator

powders, and the magnetic-field measurements using the Hall effect probe.—T.G.

Influence of plastic deformation on the time-decrease of permeability in transformer steel A. Smolinski, Z. Kaczkowski, and M. Zbikowski (*Archiwum Elektrotechn.*, 1959, **8**, (2), 333–339) Samples hot-rolled from the mill and stretched in a tensile testing machine were examined. A typical wavy curve of time-decrease of permeability is obtained, explained by variation in length of path of diffusing impurities.

On the workability of permanent magnet materials. I. Relation between magnetic and mechanical properties of the transformation-type magnet alloys Y. Kimura (*Tetsu to Hagane*, 1959, **45**, Aug., 804–808) Magnet alloys of the quench-hardening, $\gamma \rightarrow \alpha$ transformation and order-disorder transformation types are considered. Phase and structural changes are correlated with magnetic hardness (coercive force) and mechanical hardness (17 refs).—K.E.J.

The electrical and magnetic properties of some low manganese low aluminium steels E. G. Ramachandran and V. Prakash (*Trans. Indian Inst. Met.*, 1959, **12**, Dec., 349–358) The electrical and magnetic properties of magnetically soft alloys containing up to 4% each of Al and Mn made in HF and direct-arc furnaces were determined. An alloy containing 3%Al and 2%Mn has properties comparable with the conventional 4%Si alloy but is easily hot worked.—A.D.H.

Concerning the measurement of magnetic properties of electro-technical steel in weak and medium fields O. N. Al'tgauzen and N. A. Semenova (*Zavods. Lab.*, 1959, (4), 426–428) The accuracy of the measurement of magnetic characteristics of electro-technical steel depends on the fact that the method of measuring and of preparing the specimen influences the results. The effect of demagnetizing the specimens after thermal treatment, of the conditions for determining the magnetic structure in the specimen and of the variations with time in permeability in weak and medium strength fields are examined.

Magnetic, electrical and mechanical properties of high-chromium steels after various thermal treatments I. A. Kuznetsov and M. N. Mikheev (*Fiz. Met. Metallov.*, 1959, (4), 513–526) The maximum temp. for quenching should be 1175–1185° because at higher temp. grain growth is observed and deposition of non-metallic inclusions along boundaries. A tempering up to 450–500° does not cause the transformation of residual austenite. Quality control in quenching by hardness measurements cannot give any results since the same hardness is obtained also with different thermal treatments. A much better control can be carried out by measuring the electrical and magnetic characteristics.

Concerning the magnetic investigation of cold-rolled textured electro-technical steel A. A. Rotman (*Zavods. Lab.*, 1959, (4), 433–434) The specimens consisted of cold-rolled textured steel in coils of different thicknesses from 0·03 to 0·35 mm of great length. The quality of the texture, under generally identical conditions of treatment, was not uniform for all specimens. In the absence of a reliable instrument to measure this anisotropy various suggestions are made and a formula is proposed for determining magnetic properties.

Defectoscopic investigation of rails in magnetic fields in motion. II. Study of the occurrence of defects and the nature of the resulting signals in the system V. V. Vlasov and A. I. Vorob'ev (*Fiz. Met. Metallov.*, 1959, (3), 341–349) The occurrence of defects and the corresponding pulses of emf given to the coil in its motion jointly with the magnetizing device over the defective spot in rails at a speed of 90 km/h has been investigated. The mechanism of the appearance of defects is explained and it has been shown that the currents set up in the rails contribute partially or totally to the production of emf pulses. It has also been shown that it is possible to separate the useful signals so as to form the emf pulses needed for detecting the defects while in motion. **13 Defectoscope for testing rails at high speeds** V. V. Vlasov, A. I. Vorob'ev, and E. I. Uspenskii ((4), 527–533) Structural diagrams and the electrical scheme are given for apparatus which can detect transversal cracks in the rails, also transversal cracks extending only to one side of the vertical axis, cracks in the butt welds, horizontal stratifications of the rails, etc. **14 Magnetic memory for rail testing** V.V.Vlasov, Yu. S. Subbotin, and V. I. Babushkin ((5), 689–693) Diagrams are given of a magnetic recording device with two recording heads so arranged in respect to the tape that on reproduction their signals remain distinct. A diagram of the reproduction device is also given.

The shape of specimens for the determination of magnetic characteristics of electro-technical steel V. V. Druzhinin (*Zavods. Lab.*, 1959, (4), 429–433) The determination of electrical and magnetic properties of electro-technical steel is carried out on 30 mm wide specimens. The specific losses of narrow strips, however, are greater than of whole sheets. To compare the specific losses of narrow strips to those of whole sheets the GOST–802–58 standard specifies renewed anneal of the narrow strips. This raises a number of problems which are considered in this article.

Magnetic method of quantitative analysis of carbon steels Ya. I. Kagan and S. V. Bronin (*Fiz. Met., Metallov.* 1959, (4), 535–542) A method is explained of determining, by the magnetic saturation of the Fe_3C; χ FexC, and ϵ FexC without their separation the quantitative ratios of the cementite, the χ- and ϵ-phases between 120 and 600°. The findings show that the χ- and ϵ-carbides are of low carbon content ($\chi > 3$) and the qualitative calculation shows for the ϵ-phase that $\chi > 4$.

Magnetic and electrical properties and hardness of high carbon alloy steels in the quenched condition M. N. Mikheev and G. S. Tomilov (*Fiz. Met. Metallov.*, 1959, (4), 543–556) The changes of the coercive force on the cryptocrystalline martensite of high carbon Cr, Mn, and W steels reflects the degree of saturation of the solid solution by carbon and alloy elements and therefore runs parallel with a change in hardness and specific electrical resistance. This makes it possible to follow the processes of the solution of the different carbide phases at high temp. by the changes in the coercive force. The investigation of the behaviour of the coercive forces and magnetization during quenching, of specimens with sharply distinct initial structures (granular pearlite or lamellar pearlite) points to a connexion between the magnetic characteristics and grain size.

Magnetic studies on binary and ternary cubic body-centred phases of aluminium with the iron-group metals M. Hohl (*Z. Metallk.*, 1960, **51**, Feb., 85–95) The susceptibilities of, *inter alia*, Fe–Al alloys in the 50–60%Fe range were studied and the results obtained are discussed in the light of recent theories. The deviation of the 60:40 Fe–Al alloy from the Curie-Weiss law is explained by a transfer of *d*-electrons of the iron atom to the common conduction band (27 refs).—T.G.

Developing a technique for producing high permeability iron aluminium alloy N. F. Dubrov (*Stal'*, 1960, (1), 50) A note from the Urals Sci. Res. Inst. for Ferrous Metals. A melting, pack-rolling, and heat-treating schedule is given.

Magnetic susceptibility of liquid alloys of copper with cobalt, iron, manganese, and chromium Y. Nakagawa (*J. Phys. Soc. Japan*, 1959, **14**, Oct., 1372–1379).

Silicon iron with cube texture H. Hesselbach (*Stahl Eisen*, 1959, **79**, Dec. 24, 1943) A review of recent publications on the magnetic properties and effects of the so-called Goss or cube structure of silicon iron. Mention is made on the production methods for obtaining this type of structure (7 refs).—T.G.

Possibilities of improving the quality of hot-rolled transformer sheet steel M. Markuszewicz and J. Groyecki (*Hutnik*, 1959, **26**, (12), 467–482) Improvement in the field of hot-rolled transformer sheet can be achieved by changing the melting process by de-gassing the molten steel *in vacuo* and by heating the partly finished product. (According to research in the USSR, heating in an enclosed space for a considerable period at 800°C of material 2·5 mm thick, with an addition of scale decreases the carbon content by 50%). Al is a harmful impurity. Also final cold-rolling with 40% reduction is used after heat treating at 1150°C and unidirectional rolling further improves quality. Magnetic properties of plates containing 2·9%Si are tabulated.

The temperature dependence of the mechanical properties of iron-rich iron–aluminium alloys F. Lihl and R. Stickler (*Arch. Eisenhüt.*, 1960, **31**, Jan., 47–57) The mechanical properties and the electrical resistivity of the iron-rich side of the Fe–Al system up to 17·2%Al were studied at temp. ranging from −178 to +1000°C. These studies were supplemented by thermal analysis and X-ray measurements. The alloy system falls into three groups, up to 4%, up to 12% and over 12%. The different behaviour of the three groups is attributed to ordering and to order-disorder transitions in the solid solutions.—T.G.

Effect of crystallographic twins on the d.c. and a.c. properties of nickel iron alloys J. E. Thompson (*Brit. J. Appl. Phys.*, 1959, **10**, Dec., 511–517) A number of 50:50 Ni–Fe alloys were prepared by powder-metallurgical methods. Degree of cold rolling and the annealing temp. were varied to obtain optimum magnetic properties after magnetic annealing. During annealing, twins varying in number, length, and thickness were produced. The effect of these twins on the coercive force and ac loss is discussed.—T.G.

The migration of components of metal solid solutions in the field of a direct current. II I. N. Frantsevich, D. F. Kalinovich, I. I. Kovenskii, and V. V. Penkovskii (*Dodatok Ukrainsk. Fiz. Zhurn.*, 1958, **3**, (1), 64–67) [In Ukrainian] Migration in a binary Fe–Mo alloy was investigated by means of the ^{99}Mo radioactive isotope with 2 and 4·5%Mo at temp. of 980, 1000, 1050, and 1100°C for different periods of heating. Mo in solution in Fe was found to migrate to the anode in a dc field at a rate directly proportional to the Mo concentration.

Automatic apparatus for classifying electro-technical steel sheets R. I. Yanus, V. V. Kubarev, Yu. A. Vdovin, and I. P. Kolpakov (*Zavods. Lab.*, 1959, (4), 480–481) A description is given of an apparatus taking 1500 + 750 mm sheets based on an improvement on an existing coercive force meter. Schematic diagrams are given.

Concerning the method of determining the properties of electro-technical steel N. G. Chernysheva (*Zavods. Lab.*, 1959, (4), 437–439) In view of the new types of electrotechnical steels introduced in the last few years it is suggested that the established standards for magnetic characteristics be enlarged. The following characteristics are recommended: The main magnetization curve under dynamical conditions; the ratio of total specific losses to the maximum magnetic induction at corresponding frequencies of the magnetization current: the limiting hysteresis cycles for different frequencies and related to the relevant parameters (coercive force residual induction; etc.); characteristics of the material under complex magnetization, i.e. simultaneous action of direct and alternating fields, fields of two frequencies or intermittent magnetization.

Method of photographing the traces obtained by ultrasonic control F. Michalski (*Centre Doc. Sidér. Circ.*, 1959, **16**, (9), 2029–2046) The photographic technique employed is described, and several examples of its industrial application are given.

Inspect hot steel blooms without slowing production (*Iron Age*, 1959, **184**, Dec. 24, 45–47) The use of betatron equipment for inspecting heavy steel sections is described. One type of unit with an output energy of 31-MeV can inspect sections up to 20 in. thick. A particularly valuable application is the testing of hot steel billets up to 12 in. thick on the roller table by throwing a radiographic picture on a television screen. This enables the extent of pipes and other faults to be determined, and the billet can be trimmed accordingly with little wastage.—D.L.C.P.

Effect of the normalized structure in medium carbon steel on mechanical properties and ultrasonic transmissibility M. Nishihara, T.

Nakano, and M. Makioka (*Tetsu to Hagane*, 1959, **45**, Aug., 799–803) The relationship between decrease of toughness and ductility (and increase of standard deviation of impact value) and coarsening of the acicular pearlite structure is examined from micro-structures; the variation of ultrasonic attenuation is similarly examined.—K.E.J.

Non-destructive quality control of grey-cast iron castings by determining their ultrasonic attenuation G. Bierwirth (*Giesserei*, 1960, **47**, Feb., 94–98) Quality control in the iron foundry by ultrasonic attenuation measurements has proved successful, particularly if a large series of the same casting is involved. For each type of casting, frequency and testing programme has to be determined beforehand. It was found that the immersion technique gives best results. While a clear relation exists between strength and attenuation of cupola iron, it was absent for iron processed in the electric furnace, i.e. special precautions have to be applied in the ultrasonic testing of castings from electro-iron.—T.G.

Research on the physics of solids by ultrasonics techniques P. G. Bordoni, I. Barducci, and M. Nuovo (*Met. Ital.*, 1959, **51**, Nov., 525–526) Research obtained at the National Research Institute for Ultrasonics are discussed. These techniques enable exact measurements to be made of variations in elastic and inelastic parameters of solids due to temp. and speed of thermoelastic transformation. Five types of study are carried out: (1) dependence of elastic and inelastic parameters on temp. and frequency; (2) study of metal alloy; (3) effect of impurities; (4) effect of magnetic fields; (5) porous metals.

Ultrasonic testing of compressor and turbine blades for fatigue cracks J. Schijve (*Aircraft Eng.*, 1959, **31**, Feb., 51–54) Special probes using surface waves were developed by attachment of auxiliary equipment to commercial probes. The work was done at the Nat. Lucht. vaartlaboratorium, Amsterdam, for the Royal Netherlands Air Force.

Ultrasonic scattering by residual stress in steel. (On the attenuation of ultrasonic waves in steel by residual stress.) V A. Takaoki (*Nippon Kinzoku*, 1959, **23**, Feb., 108–112) The tests were performed on quenched specimens by an impulse-echo technique and were supplemented by tests during tensile and compression stressing. It was found that residual stresses change the velocity of sound. The velocity of the ultrasonic waves decreases with the stress in tensile tests and increases in compression. The legends of the Tables are in English, and as these show, the effects are rather small.

The application of ultrasonic testing to chill castings R. Ziegler and R. Gerstner (*Giesserei*, 1960, **47**, March 10, 112–117) The use of ultrasonic testing methods for the study and inspection of chill castings, particularly chill rolls, is described under the following headings: Determination of the chill zone, determination of Young's modulus, determination of the spheroidal-graphite portion in the chill zone of chilled, spheroidal-graphite cast irons, and the detection of casting effects. In the determination of the depth of the chill zone it was found that separate probe heads for transmission and reception are best suited and that the frequency must be high, 6 Mc/s or more.—T.G.

Non-destructive, ultrasonic determination of various properties of cast iron R. Gerstner (*Maschinenwelt Elektr.*, 1960, **15**, March, 79–84) The author reviews the applications of ultrasonic methods to the determination of Young's modulus, of the quantity, grain size, and shape of the graphite, of the (carbon) saturation, and of the tensile strength.—T.G.

Ultrasonic measurement of wall thickness W. Kretz (*Maschinenwelt, Elektr.*, 1960, **15**, March, 57–58) The measurement of wall thicknesses, for instance of vessels in the chemical industry which are subjected to corrosion and which cannot be inspected from the inside, is described. The main features are: square-wave impulses and a rather high frequency of 10 Mc/s.—T.G.

Ultrasonic control of welded rivets A. F. Erashov and V. M. Anfimov (*Svar. Proizv.*, 1959, (3), 35–37) This method is based on the screening effect of bottom pulses. A description of the apparatus with a block diagram is given. Over 100 tests have shown that the defects of welded rivets can be detected in a surface area of 0·3–0·4 cm^2 and over.

X-Ray analysis of 18–8 Cr–Ni stainless steel T. Kawasaki and G. Shinoda (*Nippon Kinzoku*, 1959, **22**, Sept., 489–492) A study on non-stabilized type 304 steel showed that ferrite formed by cold-working disappeared almost completely after annealing for 40 min. above 400°C. The fact that hardness was not restored after annealing at 850°C may be connected with pptn. of carbide.—K.E.J.

Radiographic investigation of niobium distribution in stainless steels L. S. Livshits and L. P Bakhrakh (*Svar. Proizv.*, 1959, (6), 20–22) To obtain resistance against intercrystalline corrosion at temperatures between 550–650°, stainless steels with increased Nb content must be used (Nb/C ≈ 10–13). Since the solution of Nb carbides at high temp. must have an unfavourable influence on the resistance to intercrystalline corrosion, quenching from temp. above 1200° must be avoided. In welding joints the zones adjoining the seam submitted unavoidably to temp. above 1300° have a lower resistance than the zones further away. The most effective measure for increasing resistance to intercrystalline corrosion is heating for 3 h to 850–900°, causing the formation of Nb carbides, thus excluding them from the solid solution of carbon.

X-Ray investigation of the phase composition of the weld metal with an austenite-ferrite structure N. Ya. Karasik (*Avtom. Svarka*, 1959, (1), 58–61) Results are given of the X-ray investigation of the phase composition of a metal of type KTI–5 in its original condition, after welding and after a few thermal treatments. The distribution of the σ-phase and of the metastable σ-phase is given. The successive phase transformations of the austenite-ferrite weld metal are shown after long exposures to heat; it can therefore be seen that the structure transformation in the α- and γ-solid solutions are unavoidable and that efforts should be directed towards obtaining such a composition as would be most resistant to the formation of the σ-phase or that the σ-phase should form at a minimum rate.

A visual X-ray method of controlling welded joints V. S. Tokmakov and G. G. Shamaeva (*Lit. Proizv.*, 1959, (8), 35–36) Apparatus is described for examining the component under a beam of X-rays which is transformed into light rays. The results of the investigation of welded joints are recorded on photographs on film taken from the screen of the converter apparatus.

Microradiography using X-rays as a means of investigating industrial materials K. Sagel (*Metall.*, 1959, **13**, Sept., 842–850) The underlying principles of transmission and reflection radiography are outlined, and several examples are described; two of these refer to ductile iron (23 refs).

An explanation of 'interference errors' occurring systematically in X-ray fluorescence spectroscopic measurements, and possible means of eliminating these errors F. Ebert and A. Wagner (**Z. Metallkunde*, 1957, **48**, (12), 646–649) Before carrying out X-ray fluorescence spectroscopy with specimens of unknown crystal structure, it is essential to determine lattice plane interferences emanating from the crystal lattice. Faulty results due to conditions in the specimen and measuring equipment are analysed in detail.

On the residual broadening of the line on the radiographs of annealed steels L. I. Mirkin (*Fiz. Met. Metallov.*, 1959, (4), 630–631) The measurements of the breadth of line on the radiographs of annealed carbon steels and steels alloyed with Cr, Mn, B, Ti, and W, have been carried out. It was found that this width appreciably exceeds the width of the line for Armco iron. The conclusion is that the dimensions of the blocks in annealed steels decrease with an increase in carbon content.

Magnetism of the electrodeposited films as revealed by electron diffraction S. Yamaguchi (*J. Electrochem. Soc.*, 1960, **107**, Jan., 55–56) An Fe film deposited on Au foil showed an effect due to its magnetic state, as did Ni also.

Metallic reinforcing screens in gammagraphy G. Courtois (*Fonderie*, 1959, July, 285–296) A survey of radioisotopes in current and occasional use or usable in γ-radiography; the construction of metallic screens with the mechanism of their reinforcement; three principles of their action in the control of electrons with their verification; and a review of the effects on the quality of the image are given.—S.H.–S.

Betatron-radiographic testing of hot steel blooms and making visible the image by means of an X-ray image-converter and a television camera W. Lückerath, K. Fink, and R. Flossmann (*Stahl. Eisen*, 1959, **79**, Oct. 29, 1637–1646) A method is described which makes possible the visualization of defects in hot blooms of 100–300 mm square actually during rolling. A 31-MeV betatron is employed as radiation source, and the image is shown on a television screen via an X-ray image converter. The limits of defect detection and the maximum speeds at which this can be carried out are discussed (39 refs).—T.G.

Material testing with radioisotopes R. Neider (*Materialprüfung*, 1959, **1**, July, 225–234) Several examples are given, including the use of labelled materials for leak detection, wear measurement, and in research and chemical analysis. Possible uses in process automation, and the use of radiography in non-destructive testing are outlined. The influence of neutron irradiation and resulting changes in irradiation of materials are discussed (27 refs).

On the utilization and the hygienic control of radioactive isotopes in the iron and steel industry H. Iijima, Y. Miyashita, and K. Toda (*J. Lab. Hyg. Iron Steel Ind.*, 1959, **8**, May, 7–17) Radiation levels and protection required for active isotopes commonly used for test purposes are discussed.—K.E.J.

Apparatus for differential thermal analysis A. A. Govorov and I. G. Grankovskii (*Zavods. Lab.*, 1959, (4), 481–482) The description is given of a special apparatus consisting of a nickel block composed of three plates built one on the other provided with openings for Pt–Pt–Rh thermocouples. This construction ensures high efficiency of thermal effects on large massive specimens at increased rates of heating and permitting the division of the specimen into small, easily heated sections. Schematic diagrams are given.

The thermal conductivity of a molten Pu–Fe eutectic (9·5 a/o Fe) J. E. Deverall (*LA–2269*, 1958, July, pp.59; from *Nucl. Sci. Abs.*, 1959, **13**, June 15, 1349) Measurements in the solid and liquid states are reported varying from 0·034 at 220°C to 0·042 at 400°C in the solid state and 0·043 at 420° to 0·046 at 520° in the molten state (in cal/cm/sec/°C).

Latest developments in high-temperature materials A. von den Steinen (*Schweiz. Arch.*, 1959, **25**, Nov., 399–408) A review dealing with high temp. steels and other alloys which have been developed during the last few years.

A short review of published information on the thermal expansion of alloys in the iron–nickel and iron–nickel–cobalt systems E. S. Smith (*RDB(R)/TN–2*, 1952, Jan. 14, pp.11; from *Nucl. Sci. Abs.*, 1959, **13**, Nov. 15, 2583).

Thermal expansion of stainless steels B. E. Neimark (*Fiz. Met. Metallov.*, 1959, (3), 389–394) A specially constructed dilatometer was used for measuring the expansion of 200 mm. long specimens by means of a sensitive device giving an accuracy of ±1 μ so that the margin of error could not exceed 1·5%. The temp. measurements gave a ±2° accuracy. The results of tests have shown that the coefficients of linear expansion of these types of steel hardly depend on the chemical composition. The findings for a number of steel types have been tabulated.

High-temperature resistance of metals. I G. Murry and J. Notin (*Bull. Cercle Etudes Mét.*, 1958, Sept., 351–380) Equations proposed by Larson and Miller, also by Dorn, for deriving long-term data from short-term creep tests are discussed critically. The theory of these two formulae is dealt with in detail and theoretical results are compared with experimental ones. Relations between time and temperature in rupture and creep tests are partly empirical and have to be supported by experimental results.—R.P.

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Possibilities of improving the quality of hot-rolled transformer sheet steel M. Markuszewicz and J. Groyecki (*Hutnik*, 1959, **26,** (12), 467–482) Improvement in the field of hot-rolled transformer sheet can be achieved by changing the melting process by de-gassing the molten steel *in vacuo* and by heating the partly finished product. (According to research in the USSR, heating in an enclosed space for a considerable period at 800°C of material 2·5 mm thick, with an addition of scale decreases the carbon content by 50%). Al is a harmful impurity. Also final cold-rolling with 40% reduction is used after heat treating at 1150°C and unidirectional rolling further improves quality. Magnetic properties of plates containing 2·9%Si are tabulated.

The temperature dependence of the mechanical properties of iron-rich iron–aluminium alloys F. Lihl and R. Stickler (*Arch. Eisenhütt.*, 1960, **31,** Jan., 47–57) The mechanical properties and the electrical resistivity of the iron-rich side of the Fe–Al system up to 17·2%Al were studied at temp. ranging from −178 to +1000°C. These studies were supplemented by thermal analysis and X-ray measurements. The alloy system falls into three groups, up to 4%, up to 12% and over 12%. The different behaviour of the three groups is attributed to ordering and to order-disorder transitions in the solid solutions.—T.G.

Effect of crystallographic twins on the d.c. and a.c. properties of nickel iron alloys J. E. Thompson (*Brit. J. Appl. Phys.*, 1959, **10,** Dec., 511–517) A number of 50:50 Ni–Fe alloys were prepared by powder-metallurgical methods. Degree of cold rolling and the annealing temp. were varied to obtain optimum magnetic properties after magnetic annealing. During annealing, twins varying in number, length, and thickness were produced. The effect of these twins on the coercive force and ac loss is discussed.—T.G.

The migration of components of metal solid solutions in the field of a direct current. II I. N. Frantsevich, D. F. Kalinovich, I. I. Kovenskii, and V. V. Penkovskii (*Dodatok Ukrainsk. Fiz. Zhurn.*, 1958, **3,** (1), 64–67) [In Ukrainian] Migration in a binary Fe–Mo alloy was investigated by means of the ^{99}Mo radioactive isotope with 2 and 4·5%Mo at temp. of 980, 1000, 1050, and 1100°C for different periods of heating. Mo in solution in Fe was found to migrate to the anode in a dc field at a rate directly proportional to the Mo concentration.

Automatic apparatus for classifying electro-technical steel sheets R. I. Yanus, V. V. Kubarev, Yu. A. Vdovin, and I. P. Kolpakov (*Zavods. Lab.*, 1959, (4), 480–481) A description is given of an apparatus taking 1500 + 750 mm sheets based on an improvement on an existing coercive force meter. Schematic diagrams are given.

Concerning the method of determining the properties of electro-technical steel N. G. Chernysheva (*Zavods. Lab.*, 1959, (4), 437–439) In view of the new types of electrotechnical steels introduced in the last few years it is suggested that the established standards for magnetic characteristics be enlarged. The following characteristics are recommended: The main magnetization curve under dynamical conditions; the ratio of total specific losses to the maximum magnetic induction at corresponding frequencies of the magnetization current; the limiting hysteresis cycles for different frequencies and related to the relevant parameters (coercive force residual induction; etc.); characteristics of the material under complex magnetization, i.e. simultaneous action of direct and alternating fields, fields of two frequencies or intermittent magnetization.

Method of photographing the traces obtained by ultrasonic control F. Michalski (*Centre Doc. Sidér. Circ.*, 1959, **16,** (9), 2029–2046) The photographic technique employed is described, and several examples of its industrial application are given.

Inspect hot steel blooms without slowing production (*Iron Age*, 1959, **184,** Dec. 24, 45–47) The use of betatron equipment for inspecting heavy steel sections is described. One type of unit with an output energy of 31-MeV can inspect sections up to 20 in. thick. A particularly valuable application is the testing of hot steel billets up to 12 in. thick on the roller table by throwing a radiographic picture on a television screen. This enables the extent of pipes and other faults to be determined, and the billet can be trimmed accordingly with little wastage.—D.L.C.P.

Effect of the normalized structure in medium carbon steel on mechanical properties and ultrasonic transmissibility M. Nishihara, T.

Nakano, and M. Makioka (*Tetsu to Hagane*, 1959, **45**, Aug., 799–803) The relationship between decrease of toughness and ductility (and increase of standard deviation of impact value) and coarsening of the acicular pearlite structure is examined from micro-structures; the variation of ultrasonic attenuation is similarly examined.—K.E.J.

Non-destructive quality control of grey-cast iron castings by determining their ultrasonic attenuation G. Bierwirth (*Giesserei*, 1960, **47**, Feb., 94–98) Quality control in the iron foundry by ultrasonic attenuation measurements has proved successful, particularly if a large series of the same casting is involved. For each type of casting, frequency and testing programme has to be determined beforehand. It was found that the immersion technique gives best results. While a clear relation exists between strength and attenuation of cupola iron, it was absent for iron processed in the electric furnace, i.e. special precautions have to be applied in the ultrasonic testing of castings from electro-iron.—T.G.

Research on the physics of solids by ultrasonics techniques P. G. Bordoni, I. Barducci, and M. Nuovo (*Met. Ital.*, 1959, **51**, Nov., 525–526) Research obtained at the National Research Institute for Ultrasonics are discussed. These techniques enable exact measurements to be made of variations in elastic and inelastic parameters of solids due to temp. and speed of thermoelastic transformation. Five types of study are carried out: (1) dependence of elastic and inelastic parameters on temp. and frequency; (2) study of metal alloy; (3) effect of impurities; (4) effect of magnetic fields; (5) porous metals.

Ultrasonic testing of compressor and turbine blades for fatigue cracks J. Schijve (*Aircraft Eng.*, 1959, **31**, Feb., 51–54) Special probes using surface waves were developed by attachment of auxiliary equipment to commercial probes. The work was done at the Nat. Lucht. vaartlaboratorium, Amsterdam, for the Royal Netherlands Air Force.

Ultrasonic scattering by residual stress in steel. (On the attenuation of ultrasonic waves in steel by residual stress.) V A. Takaoki (*Nippon Kinzoku*, 1959, **23**, Feb., 108–112) The tests were performed on quenched specimens by an impulse-echo technique and were supplemented by tests during tensile and compression stressing. It was found that residual stresses change the velocity of sound. The velocity of the ultrasonic waves decreases with the stress in tensile tests and increases in compression. The legends of the Tables are in English, and as these show, the effects are rather small.

The application of ultrasonic testing to chill castings R. Ziegler and R. Gerstner (*Giesserei*, 1960, **47**, March 10, 112–117) The use of ultrasonic testing methods for the study and inspection of chill castings, particularly chill rolls, is described under the following headings: Determination of the chill zone, determination of Young's modulus, determination of the spheroidal-graphite portion in the chill zone of chilled, spheroidal-graphite cast irons, and the detection of casting effects. In the determination of the depth of the chill zone it was found that separate probe heads for transmission and reception are best suited and that the frequency must be high, 6 Mc/s or more.—T.G.

Non-destructive, ultrasonic determination of various properties of cast iron R. Gerstner (*Maschinenwelt Elektr.*, 1960, **15**, March, 79–84) The author reviews the applications of ultrasonic methods to the determination of Young's modulus, of the quantity, grain size, and shape of the graphite, of the (carbon) saturation, and of the tensile strength.—T.G.

Ultrasonic measurement of wall thickness W. Kretz (*Maschinenwelt, Elektr.*, 1960, **15**, March, 57–58) The measurement of wall thicknesses, for instance of vessels in the chemical industry which are subjected to corrosion and which cannot be inspected from the inside, is described. The main features are: square-wave impulses and a rather high frequency of 10 Mc/s.—T.G.

Ultrasonic control of welded rivets A. F. Erashov and V. M. Anfimov (*Svar. Proizv.*, 1959, (3), 35–37) This method is based on the screening effect of bottom pulses. A description of the apparatus with a block diagram is given. Over 100 tests have shown that the defects of welded rivets can be detected in a surface area of 0·3–0·4 cm² and over.

X-Ray analysis of 18–8 Cr–Ni stainless steel T. Kawasaki and G. Shinoda (*Nippon Kinzoku*, 1959, **22**, Sept., 489–492) A study on non-stabilized type 304 steel showed that ferrite formed by cold-working disappeared almost completely after annealing for 40 min. above 400°C. The fact that hardness was not restored after annealing at 850°C may be connected with pptn. of carbide.—K.E.J.

Radiographic investigation of niobium distribution in stainless steels L. S. Livshits and L. P Bakhrakh (*Svar. Proizv.*, 1959, (6), 20–22) To obtain resistance against intercrystalline corrosion at temperatures between 550–650°, stainless steels with increased Nb content must be used (Nb/C≈ 10–13). Since the solution of Nb carbides at high temp. must have an unfavourable influence on the resistance to intercrystalline corrosion, quenching from temp. above 1200° must be avoided. In welding joints the zones adjoining the seam submitted unavoidably to temp. above 1300° have a lower resistance than the zones further away. The most effective measure for increasing resistance to intercrystalline corrosion is heating for 3 h to 850–900°, causing the formation of Nb carbides, thus excluding them from the solid solution of carbon.

X-Ray investigation of the phase composition of the weld metal with an austenite ferrite structure N. Ya. Karasik (*Avtom. Svarka*, 1959, (1), 58–61) Results are given of the X-ray investigation of the phase composition of a metal of type KTI–5 in its original condition, after welding and after a few thermal treatments. The distribution of the σ-phase and of the metastable σ-phase is given. The successive phase transformations of the austenite-ferrite weld metal are shown after long exposures to heat; it can therefore be seen that the structure transformation in the α- and γ-solid solutions are unavoidable and that efforts should be directed towards obtaining such a composition as would be most resistant to the formation of the σ-phase or that the σ-phase should form at a minimum rate.

A visual X-ray method of controlling welded joints V. S. Tokmakov and G. G. Shamaeva (*Lit. Proizv.*, 1959, (8), 35–36) Apparatus is described for examining the component under a beam of X-rays which is transformed into light rays. The results of the investigation of welded joints are recorded on photographs on film taken from the screen of the converter apparatus.

Microradiography using X-rays as a means of investigating industrial materials K. Sagel (*Metall.*, 1959, **13**, Sept., 842–850) The underlying principles of transmission and reflection radiography are outlined, and several examples are described; two of these refer to ductile iron (23 refs).

An explanation of 'interference errors' occurring systematically in X-ray fluorescence spectroscopic measurements, and possible means of eliminating these errors F. Ebert and A. Wagner (**Z. Metallkunde*, 1957, **48**, (12), 646–649) Before carrying out X-ray fluorescence spectroscopy with specimens of unknown crystal structure, it is essential to determine lattice plane interferences emanating from the crystal lattice. Faulty results due to conditions in the specimen and measuring equipment are analysed in detail.

On the residual broadening of the line on the radiographs of annealed steels L. I. Mirkin (*Fiz. Met. Metallov.*, 1959, (4), 630–631) The measurements of the breadth of line on the radiographs of annealed carbon steels and steels alloyed with Cr, Mn, B, Ti, and W, have been carried out. It was found that this width appreciably exceeds the width of the line for Armco iron. The conclusion is that the dimensions of the blocks in annealed steels decrease with an increase in carbon content.

Magnetism of the electrodeposited films as revealed by electron diffraction S. Yamaguchi (*J. Electrochem. Soc.*, 1960, **107**, Jan., 55–56) An Fe film deposited on Au foil showed an effect due to its magnetic state, as did Ni also.

Metallic reinforcing screens in gammagraphy G. Courtois (*Fonderie*, 1959, July, 285–296) A survey of radioisotopes in current and occasional use or usable in γ-radiography; the construction of metallic screens with the mechanism of their reinforcement; three principles of their action in the control of electrons with their verification; and a review of the effects on the quality of the image are given.—S.H.–S.

Betatron-radiographic testing of hot steel blooms and making visible the image by means of an X-ray image-converter and a television camera W. Luckerath, K. Fink, and R. Flossmann (*Stahl. Eisen*, 1959, **79**, Oct. 29, 1637–1646) A method is described which makes possible the visualization of defects in hot blooms of 100–300 mm square actually during rolling. A 31-MeV betatron is employed as radiation source, and the image is shown on a television screen via an X-ray image converter. The limits of defect detection and the maximum speeds at which this can be carried out are discussed (39 refs).—T.G.

Material testing with radioisotopes R. Neider (*Materialprüfung*, 1959, **1**, July, 225–234) Several examples are given, including the use of labelled materials for leak detection, wear measurement, and in research and chemical analysis. Possible uses in process automation, and the use of radiography in non-destructive testing are outlined. The influence of neutron irradiation and resulting changes in irradiation of materials are discussed (27 refs).

On the utilization and the hygienic control of radioactive isotopes in the iron and steel industry H. Iijima, Y. Miyashita, and K. Toda (*J. Lab. Hyg. Iron Steel Ind.*, 1959, **8**, May, 7–17) Radiation levels and protection required for active isotopes commonly used for test purposes are discussed.—K.E.J.

Apparatus for differential thermal analysis A. A. Govorov and I. G. Grankovskii (*Zavods. Lab.*, 1959, (4), 481–482) The description is given of a special apparatus consisting of a nickel block composed of three plates built one on the other provided with openings for Pt–Pt–Rh thermocouples. This construction ensures high efficiency of thermal effects on large massive specimens at increased rates of heating and permitting the division of the specimen into small, easily heated sections. Schematic diagrams are given.

The thermal conductivity of a molten Pu–Fe eutectic (9·5 a/o Fe) J. E. Deverall (*LA–2269*, 1958, July, pp.59; from *Nucl. Sci. Abs.*, 1959, **13**, June 15, 1349) Measurements in the solid and liquid states are reported varying from 0·034 at 220°C to 0·042 at 400°C in the solid state and 0·043 at 420° to 0·046 at 520° in the molten state (in cal/cm/sec/°C).

Latest developments in high-temperature materials A. von den Steinen (*Schweiz. Arch.*, 1959, **25**, Nov., 399–408) A review dealing with high temp. steels and other alloys which have been developed during the last few years.

A short review of published information on the thermal expansion of alloys in the iron–nickel and iron–nickel–cobalt systems E. S. Smith (*RDB(R)/TN–2*, 1952, Jan. 14, pp.11; from *Nucl. Sci. Abs.*, 1959, **13**, Nov. 15, 2583).

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Magnetic susceptibility of liquid alloys of copper with cobalt, iron, manganese, and chromium Y. Nakagawa (*J. Phys. Soc. Japan*, 1959, **14,** Oct., 1372–1379).

Silicon iron with cube texture H. Hesselbach (*Stahl Eisen*, 1959, **79,** Dec. 24, 1943) A review of recent publications on the magnetic properties and effects of the so-called Goss or cube structure of silicon iron. Mention is made on the production methods for obtaining this type of structure (7 refs).—T.G.

Possibilities of improving the quality of hot-rolled transformer sheet steel M. Markuszewicz and J. Groyecki (*Hutnik*, 1959, **26,** (12), 467–482) Improvement in the field of hot-rolled transformer sheet can be achieved by changing the melting process by de-gassing the molten steel *in vacuo* and by heating the partly finished product. (According to research in the USSR, heating in an enclosed space for a considerable period at 800°C of material 2·5 mm thick, with an addition of scale decreases the carbon content by 50%). Al is a harmful impurity. Also final cold-rolling with 40% reduction is used after heat treating at 1150°C and unidirectional rolling further improves quality. Magnetic properties of plates containing 2·9%Si are tabulated.

The temperature dependence of the mechanical properties of iron-rich iron–aluminium alloys F. Lihl and R. Stickler (*Arch. Eisenhütt.*, 1960, **31,** Jan., 47–57) The mechanical properties and the electrical resistivity of the iron-rich side of the Fe–Al system up to 17·2%Al were studied at temp. ranging from −178 to +1000°C. These studies were supplemented by thermal analysis and X-ray measurements. The alloy system falls into three groups, up to 4%, up to 12% and over 12%. The different behaviour of the three groups is attributed to ordering and to order-disorder transitions in the solid solutions.—T.G.

Effect of crystallographic twins on the d.c. and a.c. properties of nickel iron alloys J. E. Thompson (*Brit. J. Appl. Phys.*, 1959, **10,** Dec., 511–517) A number of 50:50 Ni–Fe alloys were prepared by powder-metallurgical methods. Degree of cold rolling and the annealing temp. were varied to obtain optimum magnetic properties after magnetic annealing. During annealing, twins varying in number, length, and thickness were produced. The effect of these twins on the coercive force and ac loss is discussed.—T.G.

The migration of components of metal solid solutions in the field of a direct current. II I. N. Frantsevich, D. F. Kalinovich, I. I. Kovenskii, and V. V. Penkovskii (*Dodatok Ukrainsk. Fiz. Zhurn.*, 1958, **3,** (1), 64–67) [In Ukrainian] Migration in a binary Fe–Mo alloy was investigated by means of the ^{99}Mo radioactive isotope with 2 and 4·5%Mo at temp. of 980, 1000, 1050, and 1100°C for different periods of heating. Mo in solution in Fe was found to migrate to the anode in a dc field at a rate directly proportional to the Mo concentration.

Automatic apparatus for classifying electro-technical steel sheets R. I. Yanus, V. V. Kubarev, Yu. A. Vdovin, and I. P. Kolpakov (*Zavods. Lab.*, 1959, (4), 480–481) A description is given of an apparatus taking 1500 + 750 mm sheets based on an improvement on an existing coercive force meter. Schematic diagrams are given.

Concerning the method of determining the properties of electro-technical steel N. G. Chernysheva (*Zavods. Lab.*, 1959, (4), 437–439) In view of the new types of electrotechnical steels introduced in the last few years it is suggested that the established standards for magnetic characteristics be enlarged. The following characteristics are recommended: The main magnetization curve under dynamical conditions; the ratio of total specific losses to the maximum magnetic induction at corresponding frequencies of the magnetization current; the limiting hysteresis cycles for different frequencies and related to the relevant parameters (coercive force residual induction; etc.); characteristics of the material under complex magnetization, i.e. simultaneous action of direct and alternating fields, fields of two frequencies or intermittent magnetization.

Method of photographing the traces obtained by ultrasonic control F. Michalski (*Centre Doc. Sidér. Circ.*, 1959, **16,** (9), 2029–2046) The photographic technique employed is described, and several examples of its industrial application are given.

Inspect hot steel blooms without slowing production (*Iron Age*, 1959, **184,** Dec. 24, 45–47) The use of betatron equipment for inspecting heavy steel sections is described. One type of unit with an output energy of 31-MeV can inspect sections up to 20 in. thick. A particularly valuable application is the testing of hot steel billets up to 12 in. thick on the roller table by throwing a radiographic picture on a television screen. This enables the extent of pipes and other faults to be determined, and the billet can be trimmed accordingly with little wastage.—D.L.C.P.

Effect of the normalized structure in medium carbon steel on mechanical properties and ultrasonic transmissibility M. Nishihara, T.

Nakano, and M. Makioka (*Tetsu to Hagane*, 1959, **45**, Aug., 799–803) The relationship between decrease of toughness and ductility (and increase of standard deviation of impact value) and coarsening of the acicular pearlite structure is examined from micro-structures; the variation of ultrasonic attenuation is similarly examined.—K.E.J.

Non-destructive quality control of grey-cast iron castings by determining their ultrasonic attenuation G. Bierwirth (*Giesserei*, 1960, **47**, Feb., 94–98) Quality control in the iron foundry by ultrasonic attenuation measurements has proved successful, particularly if a large series of the same casting is involved. For each type of casting, frequency and testing programme has to be determined beforehand. It was found that the immersion technique gives best results. While a clear relation exists between strength and attenuation of cupola iron, it was absent for iron processed in the electric furnace, i.e. special precautions have to be applied in the ultrasonic testing of castings from electro-iron.—T.G.

Research on the physics of solids by ultrasonics techniques P. G. Bordoni, I. Barducci, and M. Nuovo (*Met. Ital.*, 1959, **51**, Nov., 525–526) Research obtained at the National Research Institute for Ultrasonics are discussed. These techniques enable exact measurements to be made of variations in elastic and inelastic parameters of solids due to temp. and speed of thermoelastic transformation. Five types of study are carried out: (1) dependence of elastic and inelastic parameters on temp. and frequency; (2) study of metal alloy; (3) effect of impurities; (4) effect of magnetic fields; (5) porous metals.

Ultrasonic testing of compressor and turbine blades for fatigue cracks J. Schijve (*Aircraft Eng.*, 1959, **31**, Feb., 51–54) Special probes using surface waves were developed by attachment of auxiliary equipment to commercial probes. The work was done at the Nat. Lucht. vaartlaboratorium, Amsterdam, for the Royal Netherlands Air Force.

Ultrasonic scattering by residual stress in steel. (On the attenuation of ultrasonic waves in steel by residual stress.) V A. Takaoki (*Nippon Kinzoku*, 1959, **23**, Feb., 108–112) The tests were performed on quenched specimens by an impulse-echo technique and were supplemented by tests during tensile and compression stressing. It was found that residual stresses change the velocity of sound. The velocity of the ultrasonic waves decreases with the stress in tensile tests and increases in compression. The legends of the Tables are in English, and as these show, the effects are rather small.

The application of ultrasonic testing to chill castings R. Ziegler and R. Gerstner (*Giesserei*, 1960, **47**, March 10, 112–117) The use of ultrasonic testing methods for the study and inspection of chill castings, particularly chill rolls, is described under the following headings: Determination of the chill zone, determination of Young's modulus, determination of the spheroidal-graphite portion in the chill zone of chilled, spheroidal-graphite cast irons, and the detection of casting effects. In the determination of the depth of the chill zone it was found that separate probe heads for transmission and reception are best suited and that the frequency must be high, 6 Mc/s or more.—T.G.

Non-destructive, ultrasonic determination of various properties of cast iron R. Gerstner (*Maschinenwelt Elektr.*, 1960, **15**, March, 79–84) The author reviews the applications of ultrasonic methods to the determination of Young's modulus, of the quantity, grain size, and shape of the graphite, of the (carbon) saturation, and of the tensile strength.—T.G.

Ultrasonic measurement of wall thickness W. Kretz (*Maschinenwelt, Elektr.*, 1960, **15**, March, 57–58) The measurement of wall thicknesses, for instance of vessels in the chemical industry which are subjected to corrosion and which cannot be inspected from the inside, is described. The main features are: square-wave impulses and a rather high frequency of 10 Mc/s.—T.G.

Ultrasonic control of welded rivets A. F. Erashov and V. M. Anfimov (*Svar. Proizv.*, 1959, (3), 35–37) This method is based on the screening effect of bottom pulses. A description of the apparatus with a block diagram is given. Over 100 tests have shown that the defects of welded rivets can be detected in a surface area of 0·3–0·4 cm^2 and over.

X-Ray analysis of 18–8 Cr–Ni stainless steel T. Kawasaki and G. Shinoda (*Nippon Kinzoku*, 1959, **22**, Sept., 489–492) A study on non-stabilized type 304 steel showed that ferrite formed by cold-working disappeared almost completely after annealing for 40 min. above 400°C. The fact that hardness was not restored after annealing at 850°C may be connected with pptn. of carbide.—K.E.J.

Radiographic investigation of niobium distribution in stainless steels L. S. Livshits and L. P Bakhrakh (*Svar. Proizv.*, 1959, (6), 20–22) To obtain resistance against intercrystalline corrosion at temperatures between 550–650°, stainless steels with increased Nb content must be used (Nb/C ≈ 10–13). Since the solution of Nb carbides at high temp. must have an unfavourable influence on the resistance to intercrystalline corrosion, quenching from temp. above 1200° must be avoided. In welding joints the zones adjoining the seam submitted unavoidably to temp. above 1300° have a lower resistance than the zones further away. The most effective measure for increasing resistance to intercrystalline corrosion is heating for 3 h to 850–900°, causing the formation of Nb carbides, thus excluding them from the solid solution of carbon.

X-Ray investigation of the phase composition of the weld metal with an austenite ferrite structure N. Ya. Karasik (*Avtom. Svarka*, 1959, (1), 58–61) Results are given of the X-ray investigation of the phase composition of a metal of type KTI–5 in its original condition, after welding and after a few thermal treatments. The distribution of the σ-phase and of the metastable σ-phase is given. The successive phase transformations of the austenite-ferrite weld metal are shown after long exposures to heat; it can therefore be seen that the structure transformation in the α- and γ-solid solutions are unavoidable and that efforts should be directed towards obtaining such a composition as would be most resistant to the formation of the σ-phase or that the σ-phase should form at a minimum rate.

A visual X-ray method of controlling welded joints V. S. Tokmakov and G. G. Shamaeva (*Lit. Proizv.*, 1959, (8), 35–36) Apparatus is described for examining the component under a beam of X-rays which is transformed into light rays. The results of the investigation of welded joints are recorded on photographs on film taken from the screen of the converter apparatus.

Microradiography using X-rays as a means of investigating industrial materials K. Sagel (*Metall.*, 1959, **13**, Sept., 842–850) The underlying principles of transmission and reflection radiography are outlined, and several examples are described; two of these refer to ductile iron (23 refs).

An explanation of 'interference errors' occurring systematically in X-ray fluorescence spectroscopic measurements, and possible means of eliminating these errors F. Ebert and A. Wagner (**Z. Metallkunde*, 1957, **48**, (12), 646–649) Before carrying out X-ray fluorescence spectroscopy with specimens of unknown crystal structure, it is essential to determine lattice plane interferences emanating from the crystal lattice. Faulty results due to conditions in the specimen and measuring equipment are analysed in detail.

On the residual broadening of the line on the radiographs of annealed steels L. I. Mirkin (*Fiz. Met. Metallov.*, 1959, (4), 630–631) The measurements of the breadth of line on the radiographs of annealed carbon steels and steels alloyed with Cr, Mn, B, Ti, and W, have been carried out. It was found that this width appreciably exceeds the width of the line for Armco iron. The conclusion is that the dimensions of the blocks in annealed steels decrease with an increase in carbon content.

Magnetism of the electrodeposited films as revealed by electron diffraction S. Yamaguchi (*J. Electrochem. Soc.*, 1960, **107**, Jan., 55–56) An Fe film deposited on Au foil showed an effect due to its magnetic state, as did Ni also.

Metallic reinforcing screens in gammagraphy G. Courtois (*Fonderie*, 1959, July, 285–296) A survey of radioisotopes in current and occasional use or usable in γ-radiography; the construction of metallic screens with the mechanism of their reinforcement; three principles of their action in the control of electrons with their verification; and a review of the effects on the quality of the image are given.—S.H.–S.

Betatron-radiographic testing of hot steel blooms and making visible the image by means of an X-ray image-converter and a television camera W. Lückerath, K. Fink, and R. Flossmann (*Stahl. Eisen*, 1959, **79**, Oct. 29, 1637–1646) A method is described which makes possible the visualization of defects in hot blooms of 100–300 mm square actually during rolling. A 31-MeV betatron is employed as radiation source, and the image is shown on a television screen via an X-ray image converter. The limits of defect detection and the maximum speeds at which this can be carried out are discussed (39 refs).—T.G.

Material testing with radioisotopes R. Neider (*Materialprüfung*, 1959, **1**, July, 225–234) Several examples are given, including the use of labelled materials for leak detection, wear measurement, and in research and chemical analysis. Possible uses in process automation, and the use of radiography in non-destructive testing are outlined. The influence of neutron irradiation and resulting changes in irradiation of materials are discussed (27 refs).

On the utilization and the hygienic control of radioactive isotopes in the iron and steel industry H. Iijima, Y. Miyashita, and K. Toda (*J. Lab. Hyg. Iron Steel Ind.*, 1959, **8**, May, 7–17) Radiation levels and protection required for active isotopes commonly used for test purposes are discussed.—K.E.J.

Apparatus for differential thermal analysis A. A. Govorov and I. G. Grankovskii (*Zavods. Lab.*, 1959, (4), 481–482) The description is given of a special apparatus consisting of a nickel block composed of three plates built one on the other provided with openings for Pt–Pt–Rh thermocouples. This construction ensures high efficiency of thermal effects on large massive specimens at increased rates of heating and permitting the division of the specimen into small, easily heated sections. Schematic diagrams are given.

The thermal conductivity of a molten Pu–Fe eutectic (9·5 a/o Fe) J. E. Deverall (*LA*–2269, 1958, July, pp.59; from *Nucl. Sci. Abs.*, 1959, **13**, June 15, 1349) Measurements in the solid and liquid states are reported varying from 0·034 at 220°C to 0·042 at 400°C in the solid state and 0·043 at 420° to 0·046 at 520° in the molten state (in cal/cm/sec/°C).

Latest developments in high-temperature materials A. von den Steinen (*Schweiz. Arch.*, 1959, **25**, Nov., 399–408) A review dealing with high temp. steels and other alloys which have been developed during the last few years.

A short review of published information on the thermal expansion of alloys in the iron–nickel and iron–nickel–cobalt systems E. S. Smith (*RDB(R)/TN*–2, 1952, Jan. 14, pp.11; from *Nucl. Sci. Abs.*, 1959, **13**, Nov. 15, 2583).

Thermal expansion of stainless steels B. E. Neimark (*Fiz. Met. Metallov.*, 1959, (3), 389–394) A specially constructed dilatometer was used for measuring the expansion of 200 mm. long specimens by means of a sensitive device giving an accuracy of ±1 μ so that the margin of error could not exceed 1·5%. The temp. measurements gave a ±2° accuracy. The results of tests have shown that the coefficients of linear expansion of these types of steel hardly depend on the chemical composition. The findings for a number of steel types have been tabulated.

High-temperature resistance of metals. I G. Murry and J. Notin (*Bull. Cercle Etudes Mét.*, 1958, Sept., 351–380) Equations proposed by Larson and Miller, also by Dorn, for deriving long-term data from short-term creep tests are discussed critically. The theory of these two formulae is dealt with in detail and theoretical results are compared with experimental ones. Relations between time and temperature in rupture and creep tests are partly empirical and have to be supported by experimental results.—R.P.

High temperature heat contents of some binary iron alloys. Tech. Note No.2 W. B. Kendall, R. L. Orr, and R. Hultgren (*AFOSR–TN*–59–524, 1959, July 1, pp.16; *AD*–216258; from

Nucl. Sci. Abs., 1959, **13**, Nov. 15, 2577) High. temp. heat content data are given for the following binary iron alloys, Co–Fe, Cr–Fe, Fe–Mn, Fe–Si. Preparation of the alloys is described.—D. L. C. P.

Measurement of the true heat capacity of heat-resistant steels V. E. Lyusternik (*Fiz. Met. Metallov.*, 1959, (3), 363–366) A method is described for measuring the heat input with a continuously heated specimen in an adiabatic envelope with automatic control. It renders possible the measurement of the actual amount of heat supplied and of the effects of the different phase-transformations of metals up to 800–900°C.

Resistance of metals to high temperatures. IV J. Hochmann (*Bull. Cercle d'Etudes Mét.*, 1959, **7**, Sept., 487–522) Recent work on steels of type 18–8, and on 'super-alloys' of three classes, austenitic, nickel, and cobalt, is statistically reviewed.—S. H.–S.

Evaluation of alloys for high temperature gear applications E. G. Jackson, C. F. Muench, E. H. Rowe, and E. H. Scott (*WADC Techn. Rep.* 58–546; *ASTIA Doc. No.* 206666; *OTS* 151625, 1958, Dec., pp.79) Bench data are reported on ten materials for use as gears to operate up to 700°F; silicone and mineral oils were used for scoring tests. Hardness, dimensional stability, impact and tooth fatigue strengths, corrosion, and resistance to surface scoring were investigated.

The effects of inelastic action on the resistance to various types of loads of ductile members made from various classes of metals. Part VIII. Eccentrically-loaded tension members made of two stainless steels tested at elevated temperatures O. M. Sidebottom, M. E. Clark, and S. Dharmarajan (*WADC Techn. Rep.* 56–330; *ASTIA Doc.* 202495, *PB* 151673, 1958, Oct., pp.53) The steels investigated were grades 304 (tested at 1 000°F) and 17–7 pH (at 1 000 and 1 200°F). The 304 steel did not creep at 1 000°F, heat-treated 17–7 pH possessed higher strength than untreated, and exhibited higher creep in 30 min. when tested at 1 000°F. Untreated 17–7 pH was found to creep a small amount at 1 000°F and much more at 1 200°F.

The effects of inelastic action on the resistance to various types of loads of ductile members made from various classes of metals. Part IX. T-section eccentrically-loaded tension members made of type 304 stainless steel and tested at 1 000°F O. M. Sidebottom and S. Dharmarajan (*WADC Techn. Rep.* 56–330; *ASTIA Doc. No.* 202496; *PB* 151674, 1958, Oct., pp.12) Investigation of the load necessary to produce a specified amount of inelastic deformation in these members at 1 000°F gave the following results: no creep was found at least for the first 30 min., and the stress–strain diagram at 1 000°F was similar to that at room temp.

High temperature tests on aircraft control cable H. J. Godfrey (*Wire Wire Prod.*, 1959, **34**, Nov., 1473–1480) An investigation into the effect of high temp. on the properties of several types of aircraft control cables is reported. Modern flight conditions are continually increasing operating temp. Tensile, creep, and fatigue properties were investigated. The following conclusions were reached: galvanized carbon steel cables were not satisfactory at 800°F; austenitic-type stainless steel cables performed relatively well up to 800°F; Inconel X was the best material tested, at temp. above 800°F; materials for use above 1 000°F have yet to be established.—D. L. C. P.

Elevated-temperature properties of modified type 347 weld metals T. J. Moore (*Weld. J.*, 1959, **38**, Dec., 4575–4745) Weld metal compositions of En58F type, and fully austenitic modifications with high carbon and high Mn, a low carbon and a 16–8–2 composition were tested in elevated temp. tensile, stress-rupture, and RPI hot ductility tests. This is the report of the final phase of a programme on the En58F type weld metals.

'Superhigh plasticity' of commercial iron under cyclic fluctuations of temperature M. G. Lozinsky and I. S. Simeonova (*Acta Met.*, 1959, **7**, Nov., 709–715) Armco iron with 0·03%C at high temp. with cyclic temp. changes formed two necks at 720–850°C. The plasticity is explained by irregular distribution of C and concentration near boundaries. This gives $\alpha \rightarrow \gamma$ transformation in carbon-rich regions.

Thermal shock tests on austenite-ferrite connectors R. Schinn and W. Ruttmann (**Mitteilungen der Vereinigung der Grosskesselbesitzer*, 1959, (57), Dec., 407–411) Tests on pressure-welded connectors, for joining austenitic steel tube to 12%Cr ferritic steel valve bodies, showed satisfactory resistance to severe thermal stresses.

General ideas on thermal shock P. Lapoujade (*Silicates Ind.*, 1958, **22**, Nov., 578–582) Various methods of thermal shock testing of refractories are reviewed and some microstructures of affected areas are discussed. It is pointed out that tests are largely empirical and that classification is only comparative (50 refs).—R. P.

The strength and deformation characteristics of metals at very low temperatures A. Kochendörfer (*Z. Metallk.*, 1960, **51**, Feb., 73–80) The temp dependence of the strength and deformation properties of metals is discussed in terms of structural changes and an attempt is made to interpret the phenomena observed in single crystals. The factors responsible for brittle fracture of ferrous and non-ferrous metals are described, and the results of recent studies reported. The problem whether the results of laboratory tests can be applied to actual structures still remains to be solved (33 refs).—T. G.

The effect of low temperatures on the strength in biaxial stressing A. Krisch (*Arch. Eisenhütt.*, 1960, **31**, Jan., 19–24) Eleven plain-C steels were tested in the normalized and aged conditions under biaxial stress at temp. between +20 and −70°C. Yield-point and ultimate tensile stress increased with falling temp. The deformation-energy hypothesis applies down to the lowest temp. measured (29 refs).—T. G.

Cathodic hydrogen diffusion in pure and zone-melted iron in the presence of sulphur S. Besnard and J. Talbot (*Rev. Mét.*, 1959, **56**, Dec., 681–692) Using radioisotope ^{35}S, distribution of S was measured by activity measurements and by autoradiography, after the addition of Na_2S to the electrolyte; penetration of S into the interior of the metal was shown even with small Na_2S additions. It is shown that the addition of traces of S, As, or Sb increases the tendency of electrolytic iron to take up cathodic H_2.

Relation between structure and diffusion characteristics of steel R. A. Ryabov and P. V. Gel'd (*Fiz. Met. Metallov.*, 1959, (5), 732–741) In the temp. range in which the decay of austenite is intensive the constant of H_2 permeability in steel increases rapidly with a simultaneous decrease in activation energy. In different steels the austenitic decay in the first stage and depending on it, the decay in the second stage, are different and are determined by the chemical composition of the steel and by the rate of cooling. This is evident from the temp. curves related to the H_2 permeability. This makes it possible to use this method to study the structure transformations and to assess the thermal treatment effect on the permeability of the steels to gases.

Investigating by means of ^{59}Fe the diffusion of iron in corundum and rutile V. I. Izvekov and K. M. Gorbunova (*Fiz. Met. Metallov.*, 1959, (5), 713–721) By two methods, absorption and removal of layers, data were obtained regarding the diffusion of iron in α-Al_2O_3 and in TiO_2. Curves have been constructed of the relation between the diffusion coefficients of iron in corundum between 900–1 100° and in rutile between 770–1 000° and diffusion into the grain volumes on the surface and along the boundaries.

Investigating the diffusion reaction of the binary systems of the type 'metal-gas' III V. I. Arkharov, E. B. Blankova, N. A. Sukhova, and R. A. Entelis (*Fiz. Met. Metallov.*, 1959, (4), 636–638) To prove the correlation between the relative role of the homopolar bonds in the reactive diffusion products and the increase in the relative role of the metalloid in the diffusion, the diffusion mechanism has been studied in the Fe–P, Co–P, Zr–S, Zr–Se, Zr–Te, and Nb–S, Nb–Se, and Nb–Te systems. Since the homopolar bonds of the compounds of the transition elements with metalloids are stronger the greater the polarization of the metalloid and the greater the metal effect on the metalloid, P, next to S in the periodic table (but to the left of it) will polarize more strongly than S, and therefore, in P compounds, the homopolar bonds will be stronger than in the case of S with the same metals. The tabulated results confirm this.

Investigating reactive diffusion in binary systems of the type metal–gas V. I. Arkharov and E. B. Blankova (*Fiz. Met. Metallov.*, 1959, (4), 569–573) The mechanism of diffusion has been investigated for the systems Ti, V, Cr, Mn, Fe, Co, and Ni with Se, and also with Te and the results tabulated under the following headings. Temp., amount of macroscopic layer, phase composition of the scale, macroscopic characteristics of the diffusion mechanism, and texture in the layers of scale.

The zone melting of iron and the determination of the distribution coefficients for carbon, phosphorus, sulphur and oxygen W. A. Fischer, H. Spitzer and M. Hishinuma (*Arch. Eisenh.*, 1960, **31**, June, 365–371) The principles of zone melting are outlined, and a description is given of the zone melting of iron in a horizontal experimental setup using sillimanite, zirconia and lime tubes. The theoretical distribution coefficient k_0 was calculated, and the values for dissolved C, P, Si and O were found to be 0·29, 0·17, 0·04, and 0·022. (19 refs).

A study of the wetting by liquid metals of solid surfaces of refractory oxides V. N. Eremenko and Yu. V. Naidich (*Zhur. Fiz. Khim.*, 1959, **33**, (6), 1238–1245) A study in a vacuum apparatus relates wettability to electroconductivity. Tin on $MgO.Cr_2O_3$–Fe_2O_4 and Fe on $(Al, Cr)_2O_3$ are included.

On the fragility of zone-melted iron at low temperatures S. Besnard and J. Talbot (*Acta. Met.*, 1959, **7**, July, 517–519) [In French] Tensile curves have been determined for polycrystalline test pieces of zone melted iron at the temperature of liquid N_2. The mode of deformation is shown to depend on the temperature of preliminary annealing. The critical temperature of treatment is a function of the impurity content of the iron.—A. G.

On the penetration of hydrogen into metals, particularly iron A. Banège-Nia (*Compt. Rend.*, 1960, **250**, Jan. 18, 524–526) A discussion of the form in which the gas diffuses and the form occluded and the mechanism of diffusion. The gas appears to diffuse as the proton and to form molecules by recombination, especially at crystal imperfections.

The effects of hydrogen on the mechanical properties of low-alloy rotor forging steels R. M. Goldhoff, S. Yukawa, and J. G. McMullin (*JISI*, 1960, **195**, July, 298–302) [This issue].

Hydrogen content and flakes in heavy steel sections D. Ya. Povolotskii and A. N. Morozov (*Nauchnye Doklady Vyssh. Shkoly, Metallurgiya*, 1959, Jan., 37–41) The distribution of H_2 was traced by means of core drillings and the effects of heat treatments on content and distribution was investigated. Rolled and forged stock of 30 pearlitic, pearlitic–martensitic, and martensitic steels were examined. More rapid heat-treating schedules are suggested.

On the pressure of hydrogen in cavities of steel F. de Kazinczy (*Acta. Met.*, 1959, **7**, July, 525–527) In steel, H_2 forms two phases, a solution in ferrite and a gas phase in voids and cavities. A thermodynamic study is presented of the effects of temperature and pressure on the equilibrium between these phases.—A. G.

Effect of hydrogen on the yielding of mild steel F. de Kazinczy (*Acta Met.*, 1959, **7**, Nov., 706–708) Luder's band-front velocities suggest that H_2 does not affect the activation energy for separating a dislocation and its atmosphere. Suppression of the upper yield point appears to be due to local stresses surrounding molecular H_2 inclusions and to facilitate formation of the first Luder's band. H_2 raises flow stress, apparently by dragging H_2 along with moving dislocations.

The heat of solution of hydrogen in metals S. Yanagisawa and A. Tsujioka (*Nippon Kinzoku*, 1959, **23**, Feb., 128–132) A theory on the generalization of the characteristics of H_2

dissolved by metals is put forward. A relation is also derived relating the heat of solution of iH_2 n a metal to its ionization energy. The dissolved H_2 may have a negative or positive character in the metal (52 refs).—T.G.

New method of investigating the effect of hydrogen on the mechanical properties of steel at high temperatures and pressures M. B. Asviyan (*Zavods. Lab.*, 1959, (8), 1000–1003) The investigation of static bending of half rings cut from tubular specimens may be considered as an independent method of assessing H_2 stability of steel because this test is very sensitive to the embrittling effect of H_2.

Investigating the variations in the hydrogen content of the steel made in 1·5 and 3 ton electric furnaces I. Dragomer, I. Tripsa, and M. Nardin (*Met. Constr. Mas.*, 1959, (9), 743–747) To reduce H_2 content the charge must be carefully selected and the scrap should not contain oily drops. The boil in 3-t furnaces with the optimum decarburizing rate is between 0·3 and 0·35%C/h. A short boil is preferable, i.e. 20–30 min. for the 3-t furnace. The deoxidation period must be reduced and the ferro-alloys must be red hot before being added to the bath.

Effect of hydrogen on the mechanical properties of cast carbon steel Yu. A. Nekhendzi and V. P. Kalenov (*Izvest. VUZ, Chernaya Met.*, 1959, (7), 101–103) In spite of the relatively low initial H_2 content (5·5 cm^3 per 100 g) it falls steadily with time in thin-walled castings (~6 mm dia.). Then for approximately 30 days it remains unchanged after having reached relatively small amounts (1·5 cm^3/100 gr.). The strength coefficients remained practically unchanged, but after 40 days these diminished slightly. The tendency to a reduction in mechanical properties by keeping beyond 40 days may be due to the role of H_2 on the properties of the steel in the as-cast condition.

The interaction between the hydrogen dissolved in steel and the dislocations Yu. V. Grdina (*Izvest. VUZ, Chernaya Met.*, 1959, (5), 69–72) The mean values of the concentration, radius, and distribution of the energy level of the proton cloud, related to the completely linear dislocations in the iron lattice, have been established. The calculations have been carried out on the assumption of high mobility of the protons in the lattice considering their interaction, and also assuming that they form the solid solution. The results may be used in the theory of directional H_2 diffusion in the formation of flakes in steel.

Nitrogen in steel as an impurity and as an alloying element (*Aciers Fins Spéc.*, 1959, **33,** Dec., 29–33) The N_2 content of steel is discussed from the point of view of manufacture and in relation to the effect of other elements. Reference is made to the grain-refining and surface-hardening properties of N_2 as well as its γ-forming property.—R.P.

Nitrided alloy steels and their application in steel metallurgy Z. Kulinski and H. Zakowa (*Hutnik*, 1959, **26,** (9), 342–351) Nitrogen used as an alloying element in alloy steels, mainly to replace Ni, has the following advantages; it enlarges the austenitic range and it reduces the critical cooling rate. The authors discuss the theoretical aspects of the phenomenon and describe the nitriding of Cr and of Cr steels.

Effect of oxygen and silicon on the solubility of nitrogen in liquid iron M. G. Frohberg (*Stahl Eisen*, 1959, **79,** Nov. 26, 1821–1822) The author compiles the results of 13 studies published between 1935 and 1959 on the solubility of N_2 in liquid iron at temp. around 1600°C and determines the effect of O_2 and Si content on the N_2 pick-up at 1 atm (14 refs).

Effect of phosphorus on the properties of heat-resisting steels. I. Effect of phosphorus addition on the properties of 18 Cr–12Ni–2Mo and 19–9DL heat-resisting steel A. Tonooka (*Tetsu to Hagane*, 1959, **45,** March, 374–376) Data are given for the effects of up to 0·333%P on the rupture strength and hardness change on ageing.—K.E.J.

The effect of small boron additions in unalloyed steels with 0·1 to 0·4%C H.-K. Gorlich and G. Stein (*Arch. Eisenhüt.*, 1959, **30,** Dec., 737–742) The effect of B as an alloying element in hypoeutectoid Fe–C alloys was investigated, in particular the influence on hardenability. It is concluded that the latter effect is attributable to a reduction in grain-boundary energy of the γ-structure caused by B (24 refs).

Effect of carbon on the properties of the cold-rolled 17:4:4 Cr–Ni–Cu type stainless steel and of copper on this type of steel which contain nitrogen R. Tanaka and A. Sato (*Nippon Kinzoku*, 1959, **23,** Feb., 104–108) The authors studied the effect of C addition up to 0·1% on 17:4:4 Cr–Ni–Cu type stainless steel and the effect of Cu addition of up to 6·6% to similar steels containing 0·17%N_2 with respect to tensile strength and corrosion of cold-rolled and age-hardened specimens. The best results were found by addition of about 4%Cu to the N_2-bearing steel.—T.G.

The solid solubilities of iron and nickel in beryllium S. H. Gelles, R. E. Ogilvie, and A. R. Kaufmann (*NMI–1207*, 1958, July, pp.36; from *Nucl. Sci., Abs.* 1959, **13,** March 15, 391) Limits between 850–1200°C were measured by X-ray analysis of diffusion couples. The value was 5·46-wt% at 1225°C. Ni and Be between 900–1200°C were also measured as 25·2-wt% at eutectoid temp. 1065°C. A new high temp. phase was found in the Be–Ni system at 36-wt%Ni.

Influence of alloy elements on hydrogen permeability of steels and binary alloys on an iron base R. A. Ryabov and P. V. Gel'd (*Chern. Metallurg.*, 1959, (2), 83–92) The majority of alloy additions investigated (C, Si, Cr, Mn, and possibly Al) reduce appreciably the rate of diffusion of H_2 in steels. In spite of the various natures of the solutions which form, the action of the additions consists essentially on the one hand, in the change of the inter-particle interaction of the ferrite lattice and the local distortion of the energy spectrum and on the other hand in the distortion of the crystal lattice by a change in the interatomic spacings. Carbon inhibits the diffusion of H_2 because of the filling up of the interspaces and the distortion of the adjoining elementary spacings. This reduces not only the solubility of H_2 but also the number of possible ways for its penetration. The effect of other additions is also explained.

Effect of various elements on the properties of '21–4N' valve steel M. Kitahara (*Tetsu to Hagane*, 1959, **45,** March, 392–394) The effects of C, Si, Ni, Mn, W, and Co on the impact values at various temp. and on the loss of weight with PbO at 1000°C are discussed.

Comparison in functions of titanium and niobium contained in stabilized austenitic stainless steel T. Ikeshima (*Tetsu to Hagane*, 1959, **45,** March, 377–380) Data presented include hot twist characteristics, creep properties, microstructure, and changes in mechanical properties during long annealing.

Effect of C, Cr, Mo, and V on the properties of 3%Cr heat-resisting steel T. Kunou (*Tetsu to Hagane*, 1959, **45,** March, 358–360) The effects on hardness after tempering, high-strength mechanical properties, and rupture times are described.—K.E.J.

Manufacture and quality of special steel tubes for high temperature and high pressure service K. Harada (*Tetsu to Hagane*, 1959, **45,** Aug., 818–825) A review dealing with types and properties of the steels and manufacturing methods.—K.E.J.

The new stainless steel 'POLDI AKM' K. Protiva (*Hutnik*, 1959, **9,** (12), 376–399) A utility stainless steel in which Ni is largely replaced by Mn (8–9%) and N_2 (0·2%) was developed, and found to be a satisfactory substitute for 18/8 steels, except in a few corrosive media in which its corrosion resistance was somewhat inferior to that of 18/8. The mechanical properties of the new steel were satisfactory.—P.F.

Heat-resisting ferritic steels P. Bettzieche (**Mitteilungen der Vereinigung der Grosskesselbesitzer*, 1958, (57), Dec., 393–397) Experiments with a Mo–V steel and a 12%Cr steel for boiler construction show that these can be used instead of austenitic steels in the temp. range 500–600°C. For high temp. plant the use of the Mo–V steel is limited to 560°C and the 12%Cr steel to 600–650°C due to scaling. For high pressures and moderate temp the two types of steel are important.

High tungsten cobalt–vanadium high-speed steel A. N. Popandopulo (*Izvest. VUZ, Chernaya Met.*, 1959, (5), 83–89) The new type R18F4K8M high-speed steel which has been evolved surpasses by a factor of 1·5–2 the efficiency of the standard steel of type R18. Instruments of this new steel must be quenched from 1240° with a holding time at this temp. at the rate of 3–4 sec/mm thickness and after tempering must be rapidly quenched (in oil). To remove stresses a short-time tempering at 400–450° must follow the high heat tempering. The steel may be used with 63–64 R_c and 66–67 R_c hardnesses as required.

Investigations on stainless steel—and titanium-base dispersions E. S. Byron, L. B. Prus, and S. W. Porembka (*WAPD–TM–80*, 1957, Oct., pp.65; from *Nucl. Sci. Abs.*, 1959, **13,** Dec. 15, 2842) Fabrication, structure, and mechanical properties of the dispersions were studied; corrosion resistance and effects of irradiation were also examined.

Study on austenitic heat-resisting steels Y. Konishi, T. Akutagawa, T. Fujita, R. Nakagawa, and Y. Otoguro (*Trans. Nat. Res. Inst. Met.*, 1959, **1,** (1), 73) Microstructures of specimens of Haynes Stellite 88, solution annealed at 1100, 1150, 1200, 1250, and 1280°C were examined, and age-hardening of specimens solution annealed at 1250°C and aged for 2000 h at 650, 700, 750, 800, and 850°C was measured. Below 700°C specimens hardened continuously during this period at 750°C maximum hardness followed by a decrease was obtained at 300 h, and above 800°C hardness diminished continuously. Time to creep rupture was longest with specimens solution annealed at 1200–1250°C, and creep rupture properties of vacuum melted steel were inferior to those of air melted samples. This may be due to decrease in N_2 content.

Resistance properties of iron–chromium aluminium alloys Sh. R. Zheleznyakova and A. S. Tishkina (*Vestnik Electropromy*, 1959, (10), 19–21) Physical and mechanical properties of OKH23YU5A and OKH27YU5A steels are examined and suggestions are made for the construction of electric heaters, with special regard to the limiting dia. of the windings in relation to the dia. of the wire.

Molybdenum-free nitriding steels S. Lubasch and K. Loose (*Technik*, 1960, **15,** Feb., 69–72) The authors review the properties and compositions of a number of Russian steels; the original papers were published in *Stal'*.—T.G.

Selection of precipitation-hardening stainless steels M. E. Holmberg (*Mach. Design*, 1959, **31,** Oct. 29, 139–140, 142) Armco 17–4 PH and other alloys are surveyed and their mechanical properties and corrosion properties are compared.

High-strength stainless steels developed for use at elevated temperatures (*Iron Coal Trades Rev.*, 1960, **180,** Jan. 8, 87) The Jethete series of high-temp. steels developed by the United Steel Companies in collaboration with Samuel Fox & Company, Ltd, are briefly reviewed.

Ultra-high tensile steel: Recent Ford research development (*Iron Coal Trades Rev.*, 1960, **180,** Jan. 22, 196) A short note on a discovery that an alloy steel of good ductility can be produced having a UTS of 400000–500000 lb/in^2 by extremely heavy mechanical working between 420 and 560°C followed by transforming to martensite and tempering.—T.G.

Superstrong steels Research Development Corp. of America (*Mach. Design*, 1959, **31,** Nov. 12, 24–25) The Bassett process of heat treatment (not disclosed) imparts mechanical properties which are tabulated to various stainless steels and other alloys.

PH 15–7Mo: More strength at elevated temperatures M. W. Marshall and H. Tanczyn (*Met. Prog.*, 1959, **75,** March, 121–125) The new stainless steel containing 2%Mo has high elevated-temp. tensile strength combined with excellent compressive yield strength and a marked resistance to creep. These properties are combined with good fabrication qualities and corrosion resistance. This steel will be used in the aircraft of the future.—T.G.

AM 350 and AM 355: Properties and heat-treatment R. A. Lula (*Met. Progr.*, 1959, **75,** March, 116–120) The composition and properties of two new semi-austenitic stainless steels AM 350 and AM 355 are described. These

steels are used for aircraft and missiles.—T.G.

Titanium and titanium alloys H. H. Weigand (*Stahl Eisen*, 1960, **80,** March 3, 301–309) Some data on steels are included (171 refs).—T.G.

Physical and mechanical properties of nine commercial precipitation-hardenable stainless steels D. A. Roberts, D. B. Roach, and A. M. Hall (*DMIC*–112; *AD*–214194; *PB*–151068, 1959, May, pp.82; from *Nucl. Sci. Abs.*, 1959, **13,** Aug. 31, 1948) Austenitic, semi-austenitic, and martensitic types were examined at room and elevated temps. for tensile and compressive properties, stress-rupture, creep, impact, shear, and fatigue values and the effects of heat treatment.

An American constructional steel, quenched and annealed, weldable and semi-stainless. U.S.S.T.I. United States Steel Corp. (*Rev. Nickel*, 1959, **25,** March–April, 27–31) Details are given of the composition, thermal treatment, and mechanical properties of USS T–I low-alloy steel. High strength coupled with good corrosion resistance favour its use for bridges, public works, etc.—A.G.

The physical metallurgy of precipitation-hardenable stainless steels D. C. Ludwigson and A. M. Hall (*DMIC*–111, *AD*–214001; *PB*–151067, 1959, April, pp.70; from *Nucl. Sci. Abs.*, 1959, **13,** Sept. 15, 2059) Classification by composition, austenite conditioning, martensite reaction and precipitation hardening, and applications to handling, heat treatment and fabrications are considered.

Are 1 million psi steels possible? V. F. Zackay (*Steel*, 1959, **145,** Oct. 26, 141–144) It is predicted that work in the fields of refractory metals and ultra-high strength alloys will lead to steels with strengths up to 10^6 psi. Progress is expected through new refining techniques like pressure melting, new alloy combinations, and hardening processes such as Ausforming.

METALLOGRAPHY

Toward a new science of metallurgy E. E. Underwood (*Battelle Tech. Rev.*, 1959, **8,** Nov., 3–8) An introduction to quantitative metallography, determining grain and particle size, fractions of phases and spacing of particles.

Some devices for quantitative metallography C. S. Smith (*Trans. Met. Soc. AIME*, 1960, **218,** Feb., 58–62) Descriptions are given of a traverse-integrating stage, of a method of determining phase boundaries in binary systems by a nomogram, and a rotating eye-piece device for collecting statistics on dihedral angles.

Polishing cloths, abrasives and supplies for metallography Buehler Ltd (*AB Met. Digest.*, 1959, **5,** (3), pp.27) A catalogue with samples. Methods are described.

Some relations between parameters of structure in the plane of the metallographic specimen surface and in the volume of metal specimens S. Drápal and V. Horálek (*Acta Techn.*, 1959, **4,** (6), 474–494) [In English] On various assumptions expression for number, size, and shape of grain, in section and in bulk are arrived at for specimens with non-uniform grain sizes. A test for goodness of fit is applied in an appendix.

The microstructure of nitrided steels B. Brandt, W. Weizel, T. M. Norén, and K. Lindbom (*Stahl Eisen*, 1959, **79,** Dec. 24, 1938–1939) Four letters. The nitriding process of steels is discussed and disputed.—T.G.

High temperature microscopy F. Gabler and W. Wurz (*Metall*, 1959, **13,** Sept., 819–823) The design of the hot stage microscope constructed for the authors by Reichert Optische Werke AG is described, and some applications are outlined, including work on pure iron.

Investigating thin metallic films in an electron-microscope A. I. Paisov and Yu. A. Skakov (*Zavods. Lab.*, 1959, (6), 710–714) The method of Saulnier and Mirand (*Comptes Rend.*, 1958, **247,** (25) , is used for preparing the metal films. The article is a review of work done abroad.

Simple method of replicating specimens of extremely small dimensions such as whisker cross sections H. Weik (*Rev. Sci. Instr.*, 1960, **31,** Jan., 71–72).

Use of a focused ionic bombardment device for the study of metals M. Azam (*Rev. Mét.*, 1960, **57,** Jan., 41–48) The design of the equipment, and its use for reducing the thickness of carbon replicas, cleaning electron microscope diaphragms and metallographic specimens, destruction of oxide layers, etc. are described.

Non-destructive methods of structural tests on metal components T. Venturelli (*Ing. Mecc.*, 1959, **8,** Nov., 53–57) The writer describes the metallographic techniques which enable tests to be carried out on metal components without damaging them. He specially recommends the 'replica technique' for use in non-destructive testing. He finally discussed experimental tests made and results obtained using this technique at the Istituto Sperimentale dei Metalli Leggeri.

New macro etch eases study of high alloy steels Carpenter Steel Co. (*Steel*, 1959, **145,** Oct. 12, 118) The etchant described consists of one part saturated copper sulphate and two parts conc. HCl at 160–170°F. This mixture does not deteriorate and can replace more hazardous mixtures on high alloy steels.—A.G.

Single-etch extraction replica method adapted for carbon films G. R. Booker and J. Norbury (*Brit. J. Appl. Phys.*, 1959, **10,** Dec., 543) A letter. The single-etch extraction replica method for isolating materials from steels possesses a number of advantages over the double-etch method, in which the second etch is performed through the replica film. The technique of the single-etch method is described.—T.G.

Effect of silicon, aluminium, nickel, copper and phosphorus on the form of inclusions from graphitizing annealing K. P. Bunin and A. K. Repin (*Lit. Proizv.*, 1959, (4), 24–30) The experimental material consisted of a Fe–C–Si alloy containing 3·20%C and 0·86%Si made with electrolytic iron from which chilled castings were produced. The form of graphitic inclusions after annealing at different temp. with addition of Si, Al, Ni, and Cu has been studied and micrographs are shown.

Counting non-metallic inclusions in steel J. V. Hardy and R. T. Allsop (*JISI*, 1960, **195,** July, 302–307) [This issue].

On the laws of the coalescence of the carbide particles in steel above point A^1 V. I. Psarev (*Chern. Metallurg.*, 1959, (2), 93–99) In this investigation of the coalescence of carbide particles above point A_1 it was possible to establish that the temp. dependence of the parameters of the coalescence agree well with experimental data from various sources. A relation has been found to exist between the coalescence parameters and the equilibrium diagram of the iron–carbon alloys and this makes it possible to describe the general process of coalescence of the carbide particles in carbon and alloy steels. In particular it was possible to establish a relation between the dispersion of the carbide phase and the displacement of the cementite–austenite equilibrium under the influence of one or other alloy addition.

Concerning the possibility of graphite crystallization from saturated homogeneous austenite N. G. Girshovich and I. N. Bogachev (*Chern. Metallurg.*, 1959, (2), 107–108) An assessment of the ideas of various investigations, prepared by the Leningrad Polytechnic Institute.

Graphite iron diffused by annealing. I J. Pomey (*Fonderie*, 1959, (163), Aug., 357–367) A study by the thermomagnetic differential method of the graphitization of cast iron and steel. **II** (Sept., 408–420, **164**) The role of Si, the need for three-fold treatment, pouring into hot and cold moulds, the micrographic relationship between martensite, cementite, and graphite, and the kinetics of nucleation of graphite are discussed. **III** (Oct., **165,** 453–462) The graphitization of cast iron, its inoculation, nucleation, activation, and autodiffusion, with effects on its mechanical properties are described.—S.H.–S.

Chemical and structural heterogeneities revealed along former grain and sub-grain boundaries in iron P. Coulomb and P. Lacombe (*Rev. Mét.*, 1958, **55,** Oct., 918–926) It is shown that impurities segregate during annealing in a α- or γ-phase along grain- or sub-grain boundaries of pure iron. On crossing the A_3 point these boundaries migrate and a net of impurities and possibly of lattice imperfections remains. Segregation is said to depend on the parameters of the grain boundary. The microstructure depends on the annealing atmosphere (14 refs).—R.P.

Solve steel 'freckle' mystery C. E. Smeltzer jun. (*Iron Age*, 1959, **184,** Sept. 10, 188–189) Using a micro-emission X-ray spectrograph, the 'freckle' blemishes in a precipitation-hardening austenitic steel have been shown to be due to the micro-segregation of Ni, Ti, and Si. The formation of such defects may be suppressed by lowering the Si content, preferably below 0·1%.—A.G.

Segregation flaws in low-alloy steels A. A. Kiselev (*Stal'*, 1959, (10), 942–946) The occurrence and causes of spotty segregation areas are considered. Gases in general, either H_2 or CO, have been held responsible for the defect. Trials in a natural gas-fuel oil heated 150-t OH furnace now suggest that H_2 is the cause. Avoiding deoxidation with Si and avoiding large additions of lime and bauxite during refining should prevent the occurrence of the defect.

Summarized proceedings of a conference on precipitation in alloys and on metal structures—London, November 1958 A. Franks and R. S. M. Revell (*Brit. J. Appl. Phys.*, 1959, **10,** Oct., 438–444) Precipitation in steels was discussed by R. W. K. Honeycombe. Jet electrolytic machining of thin steel foils by P. M. Kelly. Order–disorder effects in Fe–Al alloys by R. W. Cahn, A. Lawley, and R. Feder. Most of the papers were non-ferrous.

On the use of tracers in the study of the enrichment in impurities of metal-oxide interfaces on steels C. de Beaulieu and M. Cagnet (*Compt. Rend.*, 1960, **250,** Jan. 18, 539–541) The accumulation of impurities is confirmed, in particular, the presence of practically all the sulphur of the oxide fraction of a Fe with 0·021%S as crystalline FeS.

Reduce carbide segregation in high speed steels J. Field (*Iron Age*, 1959, **184,** Dec. 31, 42–43) Reference is made to past and current work to illustrate that carbon segregation in high-speed steels can be minimized by pouring into short stubby moulds at low temp. and adding nucleants.—D.L.C.P.

Investigating the agglomeration of carbides in carbon steels V. I. Psarev (*Fiz. Met. Metallov.*, 1959, (4), 551–558) From a consideration of the relation between the average dimensions of carbide particles and the duration of isothermal heating and hence from a determination of the parameters of agglomeration it was possible to establish the approximate relation of the agglomeration parameters and temp. which are confirmed by experimental data of the agglomeration of carbide particles in steels above the critical point A_1. Certain aspects of these investigations require further study.

Carbide analysis of white iron I. E. Lev (*Zavods. Lab.*, 1959, (6), 656–658) A metallographic specimen of white iron covered with a phenolic resin layer leaving open only a narrow slit, was immersed in an electrolyte and the ferrite potential measured. The specimen was then selectively dissolved to a certain depth ensuring the preservation of cementite. This method is described and the results of the analysis show that best conditions for a carbide analysis are a current density of 10–15 ma/cm^2 with a 0·3N HCl solution as electrolyte for a period of 3 h.

The growth of precipitates R. G. Baker, D. G. Brandon, and J. Nutting (*Phil. Mag.*, 1959, **4,** Dec., 1339–1345) The formation of precipitates in the solid stage generates stresses which may lead to non-coherence. Mechanisms involving interstitials and vacancies and the production of dislocations are suggested. The case of face-centred cubic crystals is treated.

Carbides in annealed and quenched high speed steels T. Malkiewicz, Z. Bojarski, and J. Foryst (*Prace Inst. Hutn.*, 1959, **11,** (5), 267–275) Electrolytic extraction, chemical analysis, and X-ray powder analysis were used to study the carbides contained in quenched and annealed high speed steels. It was found that there was considerable variation in the composition and amount of carbides though in all cases the predominant carbide was M_6C.

Details of other carbides present are given. In a lengthy discussion of results the composition and quantity of the vraious carbides is related to the heat treatment.

Study on carbides in commercial special steels by electrolytic isolation. X. On carbides in Cr–Mo–V hot working tool steels T. Nishizawa (*Tetsu to Hagane*, 1959, **45,** March, 332–334) Metallographic, X-ray, and hardness data for HWD–1, –2, –3, and –11 steels (analyses given) are discussed and compared with those from SKD–1 and SKD–4 steels. The carbides are: HWD–1, $M_{23}C_6+M_6C(+MC)$; WHD–2 and –11; $M_{23}C_6+M_6C+MC$; HWD–4: $M_6C+M_{23}C_6(+MC)$.—K.E.J.

Study on the carbides in high speed steels by electrolytic isolation. III. Behaviour of the carbides due to heat-treatment in the high-W high-Co high speed steel H. Harada (*Tetsu to Hagane*, 1959, **45,** March, 338–339) Metallographic analysis of carbides and matrix are given for various tempering temp. in the range 300–750°C; the variations of concn. of the elements in the carbides are also shown.—K.E.J.

Study on the segregation of phosphorus in steel ingots Y. Harada (*Tetsu to Hagane*, 1959, **45,** March, 257–259) The segregation is studied by chemical analysis, a ^{32}P tracer technique, and auto-radiography.—K.E.J.

On the segregations in the top-cores of rimmed steel ingots. I. On research for the cause of segregation H. Takebayashi (*Tetsu to Hagane*, 1959, **45,** March, 304–306).—K.E.J.

Studies on nonmetallic inclusions in steel. I. Carbide in titanium steel T. Yanagihara, H. Kimura, and M. Chiba (*Trans. Nat. Res. Inst., Met. Tokyo*, 1959, **1,** (1), 76) A brief abstract of a Japanese report. Non-metallic inclusions were isolated in a Klinger–Koch apparatus from vacuum-melted pure Fe–Ti–C alloys. In this system Ti forms a δ-compound with NaCl-type cubic structure, and having a wide range of solid solubilities of C and Fe. This compound contains 74%Ti, 10%Fe, and 16%C, and is in equilibrium with α-iron and cementite in Ti steel.

Electron microscopical observation of A-type nonmetallic inclusions in ball-bearing steel K. Deguchi, T. Nishimura, and H. Suyama (*Tetsu to Hagane*, 1959, **45,** July, 705–712) The inclusions were classified in two groups, typified by α-cristobalite+rhodonite and manganese sulphide alone or with ferrous sulphide. Hence silicate type inclusions coexist in the range between SiO_2 and $MnO.SiO_2$, and sulphide inclusions in the range between FeS and MnS in the MnS–FeS system.—K.E.J.

Study on the non-metallic inclusions in killed steel by the point-counting method E. Nishimura (*Tetsu to Hagane*, 1959, **45,** March, 324–326) Relationships are shown between areas of inclusions and ladle life, [Mn]/[S] ratio in the ladle, and time from tap to pour.—K.E.J.

Consideration on the new secondary phase T. Masumoto (*Tetsu to Hagane*, 1959, **45,** March, 387–389) X-Ray data, mainly for η and κ-carbides, obtained from LCN–155 are analysed.—K.E.J.

Correlation between the new secondary phase and additional elements and its age-hardening T. Masumoto (*Tetsu to Hagane*, 1959, **45,** March, 389–392) The effects of addition of C, N, and (Mo+W) on the formation of a new carbide in LCN–155 are discussed.—K.E.J.

Decomposition of the carbide phase of white iron cementite under the action of a neutron stream I. M. Pronman, V. A. Shalashov, A. Kh. Breger, and Yu. A. Zubov (*Doklady AN*, 1959, **127,** (6), 1259–1262) Pure cementite was eliminated from the white cupola iron by electrolytic carbide deposition. The specimens, Al ampoules with pure cementite, were placed in the active zone of a nuclear reactor with water and enriched U in a stream of 10^{12} neutrons/cm^{2}sec. screened to absorb the thermal neutrons. As result of the neutron radiation iron nuclei formed which after a subsequent anneal at temp. below the austenitic domain crystallized as α–Fe and at temp. corresponding to the austenitic domain as γ–Fe with in the latter case, formation of residual austenite.

Electron-microscopical and electronographic investigation of the carbide particles in austenitic stainless steel transformations V. V. Levitin and G. D. Susloparov (*Doklady AN*, 1959, **129,** (2), 318–320) The carbide particles develop along the grain boundaries because of a decrease in the activation energy of the process of decay of the supersaturated solid solution. The particles assume branched dendritic shapes because of the disturbance of the diffusion processes at the temperature of pouring.

Ternary carbides of the transition metals nickel, cobalt, iron and manganese with gallium H. H. Stadelmaier, L. J. Hutter, and N. C. Kothari (*Z. Metallkunde*, 1960, **51,** Jan., 41–45) Ternary compounds of the type T_3CaC_x were found in the systems Co–Ga–C and Fe–Ga–C, having an ordered face-centred cubic lattice, and forming part of a group of phases in which Ga is replaced by Mg, Al, Zn, Ga, In, or Sn (24 refs).

Elimination of non-metallic inclusions from the surface of the polished microsection V. I. Shevchenko and E. I. Alpatov (*Zavods. Lab.*, 1959, (4), 442–444) The method proposed is based on the anodic solution of a small quantity of metal with inclusions visible in the microscope on the surface of the polished microsection. These inclusions can then be separately analysed under the microscope or petrographically, chemically, or by X-rays. The special arrangement for the cathodic solution is explained with schematic diagrams.

Scale for estimating inclusions in rolled steel material of the type of titanium nitrides E. P. Akimova, V. I. Shevchenko, and E. N. Alpatov (*Zavods. Lab.*, 1959, (4), 444–445) Ti nitrides in steel often form inclusions in the form of lines reaching sometimes over a considerable length and width. In order to be able to assess the degree of contamination by these inclusions a scale is proposed which considers frequency, length, and area.

Revealing interdendritic non-metallic layers in cast steel N. A. Ermanovich, M. F. Louginov, L. G. Orlov, and L. M. Utevskii (*Zavods. Lab.*, 1959, (4), 440–442) When certain specimens of a few structural steels are fractured some defects are noticed along the original boundaries with deformation of macroscopic relatively smooth surfaces at the place of rupture. Metallographic spectral and X-ray analysis has shown that nitrides concentrate along the boundaries, mainly of Al, which cause weakening. This has been confirmed in experiments with the electron microscope, and the presence of a sufficiently coarse layer (in all probability a multi-layer) between crystals of the steels investigated, has been found. It probably consists of AlN, VN, TiN, $Fe_3Al_2(SiO_4)_3$, and other phases.

The nature of bright and dark spots in the macrostructure of steel I. P. Zabaluev and L. B. Kissina (*Stal'*, 1959, (12), 1121–1123) The spots appear on etching with 1:1 HCl at 50–60°. Samples from 15 heats of seven grades of steel were examined after rolling and an ingot of ShKh15 in the cast state. Bright spots in finely crystalline regions free from impurities are not grounds for rejection. Dark spots in contaminated areas of coarse structure are signs of defects in the metal. In arc-heated feeder heads overheating must be avoided to prevent dark spot formation.

The use of controlled solidification in equilibrium-diagram studies W. A. Tiller (*Trans. Met. Soc. AIME*, 1959, **215,** Aug., 555–559) It is shown theoretically that the use of controlled solidification makes possible the determination of liquidus and solidus surfaces together with tie-lines for a polycomponent alloy.—A.G.

New method of studying solidification processes G. F. Zasetskii and V. A. Shakhnovich (*Lit. Proizv.*, 1959, (4), 34–35) A method is described of following the crystallization processes by means of radioactive isotopes which makes it possible to investigate the process under various conditions of temperature and in different moulds.

The non-uniform distribution of elements in white iron I. E. Lev (*Lit. Proizv.*, 1959, (5), 36) The distribution of the elements affects the properties of the white iron. Experiments have shown that after solidification, the different elements are not uniformly distributed between phases nor between the microparticles of the matrix. The diffusion rate is therefore determined not by carbon but by the alloy elements.

Orientation superstructures of Fe–Co alloys E. T. Ferguson (*J. Phys. Radium*, 1959, **20,** Feb., 251–253) Measurements of the magnetic anisotropy of a 50%Fe–Co alloy after various heat treatments in a magnetic field are reported. These show that the appearance of a normal superstructure reduces the induced uniaxial magnetic anisotropy, in agreement with theory.—A.G.

Orientation superstructures produced by mechanical deformation of an Fe–Ni alloy R. Vergne (*J. Phys. Radium*, 1959, **20,** Feb., 254–257) It is shown that directional ordering is produced by annealing stressed Fe–Ni alloys. Results of measurements of the energy needed to give saturation as a function of stress are interpreted by means of Néels theory.—A.G.

Relation between austenitic grain size and aluminium nitride. V. Austenitic grain structure and aluminium nitride during heating process S. Nagata (*Tetsu to Hagane*, 1959, **45,** March, 326–328).—K.E.J.

The effect of weak plastic deformation on the secondary recrystallization and texture formation of cold-rolled transformer steels L. V. Mironov and Ya. S. Shwartsbart (*Fiz. Met. Metallov.*, 1959, (4), 631–632) The specimens after a 2 h tempering at 800° were rolled with a reduction of 2·5, 5, 7·5, and 10% and tempered at different temp. from 700 to 1100°. As a result of the findings it can be said that after rolling with the reduction mentioned no secondary recrystallization was observed, but only the normal crystallization due to the treatment. The grain sizes are conditioned by the degree of reduction and the temp. of the subsequent tempering.

Grain growth in silicon iron P. K. Koh (*Trans. Met. Soc. AIME*, 1959, **215,** Dec., 1043–1048) Normal grain growth did not take place during salt-bath annealing of 3%Si-iron sheet at 927–1260°C, instead nucleated grain growth prevailed. The nucleation frequency was found to increase with temp. with a corresponding decrease in grain dia. of ultimate secondaries after long-time annealing. The mechanisms of grain growth and texture development are discussed.—T.G.

The growth of proeutectoid cementite in steels, interim report No.1 R. W. Heckel and H. W. Paxton (*OOR* 1922: 1, 1959, Feb. 28, pp.231; from *Nucl. Sci. Abs.*, 1959, **13,** Nov. 15, 2582) Work comprising a metallographic survey of the precipitation of proeutectoid cementite from hypereutectoid steels is reported.—D.L.C.P.

Preferred orientation in warm-worked and heat-treated 4340 steel E. B. Kula and S. L. Lopata (*Trans. Met. Soc. AIME*, 1959, **215,** Dec., 980–985) Yield and ultimate tensile strength vary with direction in heat-treated 4340 steel which had been warm-worked by rolling in the austenitic condition before quenching. X-Ray analysis showed a preferred orientation of martensite crystals. The observed martensite pole figures are reproduced and discussed.—T.G.

Polygonisation C. Crussard (*Metall*, 1960, **14,** Jan., 12–20) A review of the literature dealing with observations of and theories of the mechanism of polygonization in metal crystals. Topics discussed include deformation and polygonization in pure bending, complex deformations, polygonization in creep, and relationships between polygonization and the original dislocation structure (52 refs).

A texture study in silicon iron P. K. Koh and C. G. Dunn (*Trans. Met. Soc. AIME*, 1960, **218,** Feb., 65–69) Annealing 3 min. at 800°C produced the primary recrystallization texture in 3%Si iron. This is described in terms of four (112) [$\bar{6}\bar{8}1$] and two (111) [112] type components. A salt bath at 1260°C produced a special texture whereas ordinary secondary annealing with a slow rise 900–1000°C produces strong (110) [001] texture. The special texture (from 325 grains) showa a moderately strong component (304) [010] and two weak (111) [$1\bar{1}0$] components.

Influence of constraints during rolling on the textures of 3%silicon iron crystals initially (001) [100] R. G. Aspden (*Trans. Met. Soc. AIME*, 1959, **215,** Dec., 986–991) A marked difference in the rolling and annealing textures was observed in 3%Si iron crystals rolled with and

without constraints. The crystals had an initial orientation of (001) [100]. The results indicate that the contribution of constraints at grain boundaries in a polycrystalline sheet should be considered in applying textural data on single crystals to grains in an aggregate (26 refs).—T.G.

The effect of aluminium on the crystallization of iron A. S. Kamevetskaya, E. P. Pakhmanova, E. Z. Spektor, and U. I. Shiryaev (*Doklady AN*, 1959, **128,** (5), 924–926) It has been established that Al introduced into iron acts as a surface-active dissolved additive, reducing the energy for the formation of crystallization centres similar to the action of dissolved additives in the crystallization of organic liquids. In the presence of such surface-active additions the growth of these centres in the volume of the melt may take place with much less cooling than is necessary for the growth on centres on foreign particles.

Demonstration of a regeneration phenomenon in single crystals of α-iron or α-uranium by persistence of nuclei during the allotropic transformations $\alpha \leftrightarrows \gamma$ in iron and $\alpha \leftrightarrows \beta$ in uranium G. Donzé and R. Faivre (*Ref. Mét.*, 1960, **57,** Jan., 16–22) The fact that a crystal of α-iron containing traces of impurities such as C or N is deformed with the original orientation after the double transformation $\alpha \rightarrow \gamma \rightarrow \alpha$, provided that the transformation temp. is only slightly exceeded, can be explained on the assumption that the nuclei of the low-temp. structure are preserved within the high-temp. structure (20 refs).

Relation between carbide precipitation and intercrystalline corrosion of titanium-bearing chromium–nickel steels V. Čihal (*Stahl Eisen*, 1959, **79,** Dec., 24, 1944–1945) This is a summary of a thesis by the author submitted to the Montanistische Hochschule Ostrava 1956. The steels used for the investigation were stabilized by Ti and the relation between corrosion and carbide precipitation on the grain boundaries were studied. The effect of σ-phase formation on intercrystalline corrosion is discussed in detail.—T.G.

Behaviour of carbides in tempered alloy steels T. Sato (*Tetsu to Hagane*, 1959, **45,** Aug., 813–817) A review, including variations of carbide content with tempering temp. in Ni–Cr, Cr–Mo, and Si–Mn steels, and changes in the composition of carbides of Cr, Mo, W, and V (8 refs).—K.E.J.

A study on the carbide precipitation of austenitic manganese steel K. Hashiura and M. Watanabe (*Nippon Kinzoku*, 1958, **22,** Nov., 557–560) Changes of structure and hardness were studied in austenitic Mn steel isothermally transformed at temp. between 400° and 900°C. Carbide formation was mainly at grain boundaries. Transformation (carbide and troostite) began earliest in the water-quenched condition, and was delayed with small quenching strains. The troostite transformation was much affected by carbide formation.—K.E.J.

A metallographic investigation on the carbide reaction in iron and steel. II. On the carbide reaction in chromium steel during isothermal tempering T. Sato, H. Kaneko, and E. Osonoi (*Nippon Kinzoku*, 1959, **22,** Sept., 484–488) The reactions in three steels (compositions given) are reported. The initial phases were all $(Fe, Cr)_3C$, and the final phases were $(Fe, Cr)_3C$, $(Cr, Fe)_7C_3$, and $(Cr, Fe)_{23}C_6$.—K.E.J.

The effect of creep deformation at 700°C on the transformation of molybdenum carbides in a ferritic steel K. A. Ridal and A. G. Quarrell (*JISI*, 1960, **195,** July, 307–314) [This issue].

Some peculiarities of carbide precipitation in ferrite E. W. Langer (*Arch. Eisenhütt.*, 1959, **30,** Nov., 683–684) By the ageing of soft iron and unalloyed steels with low C contents at temp. up to 200°C the cementite is precipitated as acicular crystals, and large numbers of fine, parallel small needles are observed, which can be assumed from examination under the electron microscope to be sigma carbide formed later than the cementite needles. The mechanism of this formation is considered.

Transformation twins in alpha iron D. S. Hutton, G. L. Coleman, W. C. Leslie (*Trans. Met. Soc. AIME*, 1959, **215,** Aug., 680–681) Attention is drawn to the prevalence of twins in alpha iron, generated during cooling through the $\gamma \rightarrow \alpha$ transformation, and illustrations of their appearance are given.—A.G.

The iron–carbon eutectoid temperature R. P. Smith and L. S. Darken (*Trans. Met. Soc. AIME*, 1959, **215,** Aug., 727–728) The eutectoid temp. has been measured by determining the temp. corresponding to the maximum rate of change of austenite decomposition products in hollow cylinders of a pure iron–carbon alloy. The value obtained was 727·2 ± 0·5°C.—A.G.

The ferrite of Widmannstätten orientation: A contribution to the transformation characteristics and strength changes of weldable structural steels A. Rose and A. Klein (*Stahl Eisen*, 1959, **79,** Dec. 24, 1901–1912) After a short historical review of the Widmannstätten structure the authors discuss the factors that affect the formation of acicular ferrite and the influence that is exercised by austenizing treatment. This is followed by a discussion on the effect of ferrite structure on hardness and impact toughness, and an attempt is made to explain the mechanism involved in the formation of acicular ferrite (26 refs).—T.G.

Comparative study of the allotropic transformations in iron and uranium and their structural consequences P. Lehr (*Univ. of Paris Thesis*, 1958, pp.73; translation *CEA*–800, from *Nucl. Sci. Abs.*, 1959, **13,** Oct. 15, 2278) The development of α-nuclei in the $\alpha \leftrightarrows \beta$ change of U and the $\alpha \leftrightarrows \gamma$ change in Fe were studied by control of interface displacement in a temp. gradient. Crystallographic orientations, crystal perfection, expansion coeff., and volume changes are considered and thermal cycling effects in both metals.

Diagrams for isothermal transformation valid for some Swedish standardized tool steels G. Molinder (*Jernkontorets Tekn. Rad. Meddelander*, 1954, **18,** (203), 263–270) *TTT*-diagrams for SIS 1880, 2092, 2140, 2260, 2310, 2312, 2550, 2705, and 2710 steels are determined. (These do not comprise any high-speed steels.) The amounts and identities of carbides present were also estimated. The work was carried out in several laboratories.

Transformational behaviour of Mn–Mo armour steels E. F. Nippes, W. F. Savage, and J. M. Paez (*Weld. J.*, 1959, **38,** Dec., 4755–4815) Continuous cooling transformation diagrams were obtained for four steels using dilatometric data. The test set-up was then used to study the effects of rate of heating associated with arc welding. Some metallographic work was also carried out.

Effect of the rate of heating during tempering on the transformations in steels A. P. Gulyaev and M. V. Taratorina (*Fiz. Met. Metallov.*, 1959, (4), 544–550) With an increased rate of heating for tempering, transformation is partially depressed which is shown both by the retention of a large amount of carbon in solution and by a reduction of the dilatometric effect of transformation. Electronic microstructure slides also show a decrease in the degree of carbide segregation. The second transformation, i.e. the decay of the residual austenite, takes place at all rates of heating investigated, although the characteristic sign of its occurrence, the positive dilatometric effect (expansion) is not observed at rates of heating exceeding 100°/sec.

Factors influencing the formation of graphite or carbon in cast iron A. Bordes (*Metalen*, 1959/1960, 14/15, No.16, 337–341; Dec. 15, 374–377, Jan. 15, 58) The first two of these instalments concern the α-, β, γ-, and δ-types of graphite segregations known as primary, eutectic, rosette, and undercooled graphites respectively. The third instalment relates to inverse chilling and hard spot formation. Numerous graphs and diagrams appear in the text together with numerous bibliographical references from the relevant technical press.

Transformation of graphite inclusions in cast iron saturated with magnesium F. N. Tavadze and M. A. Essen (*Lit. Proizv.*, 1959, (6), 15–18) This is an attempt to clarify the theoretical problem concerning the mechanism of the formation of spheroidal graphite and the results of the experiments here reported, using Mg, Al, Cu, and Li, have shown that for the transformation of graphitic inclusions, pressure is necessary and also certain properties of the diffusing element.

The effect of chromium on the stability of cementite G. Sandoz (*Trans. Met. Soc. AIME*, 1959, **215,** Dec., 1052–1056) The author demonstrated on a simple diffusion-couple experiment that sufficient Cr may make cementite thermodynamically stable relative to graphite and austenite in cast irons at 1750°F. He discusses the implications of these results for some current theories of graphitization mechanisms (18 refs).—T.G.

The solubility of cementite in austenite R. P. Smith (*Trans. Met. Soc. AIME*, 1959, **215,** Dec., 954–957) Solubility measurements were made on specially prepared Fe–C alloys containing a single-phase austenite and a two-phase austenite + cementite region in the temp. range 734–1012°C. The mean heat of solution of cementite in austenite was found to be 7560 cal/mol, and the eutectoid composition of austenite to contain 0·765%C.—T.G.

Influence of cobalt on the transformation of a chromium alloyed austenite P. Nicolaides, D. Coutsouradis, and L. Habraken (*Trans. Met. Soc. AIME*, 1959, **215,** Aug., 702–705) The effect of up to 12%Co on a 0·1%C, 13%Cr steel has been investigated. Co increases the incubation time and decreases the transformation rate. In addition, the bainitic transformation is displaced to a lower temperature.—A.G.

The role of austenitizing temperature in the nucleation of pearlite M. H. Richman, D. A. Thomas, and M. Cohen (*Acta Met.*, 1959, **7,** Dec., 814–816) A letter. Experiments are described which show that the low rate of pearlite nucleation which is characteristic of a high austenitizing temp. may be progressively increased as that temp. is lowered. The results indicate that there is a reversible phenomenon in the austenitizing treatment apart from any possible effect of austenite grain growth or dissipation of macroscopic concentration gradients.—D.L.C.P.

Some observations on the stability of austenite in Hadfield-type manganese steel S. N. Mookerjee, H. R. S. Rao, V. G. Paranjpe, and S. Visvanathan (*Trans. Indian Inst. Met.*, 1959, **12,** Dec., 371–385; discussion, 385–386) The distance from the quenched end that austenite remains in the standard Jominy test is shown to be a measure of austenite stability in 14%Mn steel. An increase in carbon content decreases the stability but N_2, B, and Ni increase stability during cooling. Homogenization of austenite increases its stability during cooling. The test is also suitable for determining the resistance of austenite to tempering.

A dilatometric investigation of the kinetics of the initial isothermal reaction in tempering martensite H. Gerdien (*Arch. Eisenhütt.*, 1959, **30,** Nov., 673–681) Conditions of the experiment are described; these include the use of small specimens previously quenched, with the measurement of the tempering occurring during heating to the experimental temp. Activation energy was found to be constant for each stage of the reaction, which however rises from about 20000 cal/mol at the commencement of tempering to more than 30000 cal/mol near the end of the first stage of tempering. The results are discussed, and in an appendix a calculation of the composition of sigma carbide shows this to lie between $Fe_{1\cdot5}C$ and $Fe_{2\cdot5}C$ (15 refs).

The effect of chemical composition on the shape of martensite transformation curves R. Brook, A. R. Entwisle, and E. F. Ibrahim (*JISI*, 1960, **195,** July, 292–298) [This issue].

The crystallographic course of martensite transformation in thin layers and in compact workpieces of iron–nitrogen or iron–carbon alloys W. Pitsch (*Arch. Eisenhütt.*, 1959, **30,** Aug., 503–512) It is shown, based on results from a previous paper by the author (*Acta Met.*, 1953, **1,** 260–281), that martensite formed by transformation in thin layers consists of fibro-crystals with a twinned orientation, the orientation relationship with austenite being: $[\bar{1}10]_A \| [11\bar{1}]_M$; $[110]_A \| (112)_M$ without the occurrence of a habit plane. This structure differs from those due to martensite transformation in compact specimens. Reasons for this difference are discussed, and it is shown that the orientation relationship becomes: $[\bar{1}10]_A \| [11\bar{1}]_M$; $(11\bar{1})_A \| (101)_M$. These relationships are compared with those already reported in the literature.

On the habit plane of the stress-induced martensite transformation in an Fe–30%Ni alloy M. Doi (*Bol. ABM*, 1959, **15**, Oct., 649–654) [In Portuguese] The author demonstrates that these habit planes can be explained by the same theory of conformity of atomic arrangement between the austenite and martensite as he advanced previously in the case of temp.-induced transformation.—P.S.

On the theory of martensitic transformations. The generalized lattice invariant shear and the degeneracy of solutions for the cubic to tetragonal transformation M. S. Wechsler (*Acta Met.*, 1959, **7**, Dec., 793–802) The theory of the crystallography of martensitic transformations is extended in terms of generalized elements for the lattice invariant shear. The criteria for K-degeneracy and g-degeneracy are developed and compared with those given by Christian as a result of geometrical treatment. Existence conditions for real solutions are also developed in terms of the generalized theory.—D.L.C.P.

Experimental evidence for martensitic embryos M. H. Richman, M. Cohen, and H. G. F. Wilsdorf (*Acta Met.*, 1959, **7**, Dec., 819–820) A letter. The application of thin-foil (transmission) electron microscopy to the investigation of martensitic embryos is described. These embryos are postulated by recent theories on the kinetics of martensitic transformations as 'frozen in' during the cooling from the austenitizing treatment. Sections of the Fe–Ni alloys investigated showed plate-like markings which were deduced to be martensitic embryos. Further experiments will correlate these observations with the actual initiation of the martensitic transformation.

Phase changes in precipitation hardening nickel-chromium-iron alloys during prolonged heating C. C. Clark and J. S. Iwanski (*Trans. Met. Soc. AIME*, 1959, **215**, Aug., 648–651) Microstructural changes have been studied in two high-temperature alloys using X-ray and electron diffraction, electron microscopy, and electron probe microanalysis. Possible mechanisms for the transformations observed are discussed.—A.G.

The sigma-phase in stainless weld metal of the 19Cr–9Mi type I. Wachtmeister (*Svetsen*, 1959, **15**, Sept., 107–115) The temp.-time relations for σ-phase formation are laid down and the effects of previous treatment and alloying elements are defined. Mo, Cr, Ni, and Si are most active; where these are high, σ-phase may form directly in welding. It is broken down on quenching from 950–1050°C. Tensile and impact data are given and embrittlement is discussed. Corrosion by HNO_3 was also examined, σ-phase being more resistant to attack.

Electron diffraction study of the sigma phase of the systems chromium–iron and chromium–nickel H. J. Schüller and P. Schwaab (*Z. Metallk.*, 1960, **51**, Feb., 31–34) Vacuum-deposited films of Cr–Fe and Cr–Ni alloys were prepared and studied by electron diffraction after careful annealing at between 300 and 1025°C in a high vacuum for up to 144 h. Sigma-phase formation was observed in the Cr–Fe system down to 350°C with certainty and down to 300°C with great probability. From this result it is concluded that it is improbable that the sigma phase decomposes as a eutectoid, definitely not above 300°C (23 refs).

Indications of phase transformation of the second order in the Fe_3Al alloy Ya. P. Selisskii (*Fiz. Met. Metallov.*, 1959, (4), 534–543) In slow cooling from the Kurnakov point the period of the lattice and the dimensions of dilatometric specimens change uniformly. The hardening and softening temp. ranges for Fe_3Al have been obtained from the data on compression and expansion of specimens measured with a dilatometer. The experimental data regarding the absence of intermittent changes of volume during hardening and softening of the Fe_3Al alloy together with data from the literature confirm that the hardening of this alloy is a phase transformation of the second order and this has been explained on the basis of the thermodynamic theory of phase transformations.

The solubility of copper in ferrite H. A. Wriedt and L. S. Darken (*Trans. Met. Soc. AIME*, 1960, **218**, Feb., 30–36) Direct saturation at 698–841°C and analysis was used. Fe and Cu containing Ag were equilibrated using iodide carried in sealed capsules. The equation $\log \%Cu = 4{\cdot}335 - 4{\cdot}499\left(\frac{1}{T}\right)$. X-ray studies of lattice dilation explain discrepancies between these and previous values.

Phase analysis of chromium–nickel–titanium steels with intermetallic toughening K. P. Sorokina, N. I. Blok, and N. F. Lashko (*Zavods. Lab.*, 1959, (6), 659–661) Methods of phase analysis are described for different types of steels based on electrolytic separation of the elements.

Separate etching of films of the double and triple phosphide eutectics in irons L. P. Zaitseva and N. P. Simasheva (*Zavods. Lab.*, 1959, (6), 705–707) The method of differentiating between double and triple phosphate eutectics was evolved from chemical and electrolytic etching of Fe–P; Fe–C, and Fe–C–P alloys. The results of these investigations are tabulated so that it was possible to evolve a method of alternate electrolytic etching in a neutral solution of $K_2Fe(CN)_6$ with a 6 V current for 30–50 sec. with subsequent etching in an alkaline solution of the same electrolyte with a 3 V current for 10–15 sec. when the separate eutectics dissolve.

1300°C isotherm in the system iron–chromium–nickel P. E. Price and N. J. Grant (*Trans. Met. Soc. AIME*, 1959, **215**, Aug., 635–637) Results of an experimental study of the Fe–Cr–Ni system at 1300°C are presented. They indicate a more restricted Cr solubility in austenite and greater solubility of iron and Ni in ferrite than was shown by earlier investigations.—A.G.

Observations on the system zirconium–iron L. E. Tanner and D. W. Levinson (*Trans. Met. Soc. AIME*, 1959, **215**, Dec., 1066–1067) A note. The authors re-examined the Zr–Fe system up to 55 wt-%Fe using high-purity materials, but a phase diagram is presented for the Zr-rich corner only. Further studies were made on the intermediate phase $ZrFe_2$, an alloy containing 54·81%Fe was nearly single-phase $ZrFe_2$ with very small amounts of retained β at the compound grain boundaries. The magnetic properties of $ZrFe_2$ were also studied, they are remarkably similar to those of nickel.—T.G.

An investigation on the titanium–iron–carbon system Y. Murakami, H. Kimura, Y. Nishimura (*Trans. Nat. Res. Inst. Met. Tokyo*, 1959, **1**, (1), 7–21) Study of the solid solubility ranges in the intermetallic compounds TiFe and $TiFe_2$ of the Ti–Fe system and phase relationships in the Ti–Fe–C system, by microscopical and radiographic techniques and melting point determinations gave the following results. Solid solubility ranges of TiFe and $TiFe_2$ were 52–54wt%Fe at 1080°C and 69–77wt%Fe at 1200°C respectively. α-Ti, β-Ti, graphite, δ-phase, TiFe, $TiFe_2$, α-Fe and γ-Fe were found as solid phases in the ternary alloy but no ternary compound was formed. Equilibrium conditions are discussed.

The system iron-titanium-phosphorus R. Vogel and B. Giessen (*Arch. Eisenhütt.*, 1959, **30**, Sept., 565–576) Chemical, thermoanalytical microscopical, and radiographic investigations, together with hardness measurements are described to determine the phase diagram Fe–Ti–P in the region Fe–FeP–TiP–Ti. The ternary compound FeTiP is discussed, together with the structure of the alloys investigated at room temp.

A compendium of constitutional ternary diagrams of the metallic systems W. Guertler (*WADC-TR-58-615* (Part I); *AD-210719*, 1958, Dec., pp.257; from *Nucl. Sci. Abs.*, 1959, **13**, Sept. 15, 2062).

Intermetallic phases occurring during diffusion in the iron–tantalum system V. D. Burlakov and V. S. Kogan (*Fiz. Met. Metallov.*, 1959, (5), 708–712) The investigations have established an intermetallic compound corresponding to the formula FeTa; a eutectic composition of 60 atom.%Ta (shown on X-ray analysis to consist chiefly of TeFa) a eutectic temp. of ~1350°; an equilibrium condition above 1400° of the Fe_2Ta compound, rich in Ta reverting to FeTa below this temp. and no gradual transition from the Fe_2Ta to the FeTa lattice.

CORROSION

Biological factors of corrosion in seawater B. Callame (*Corros. Anticorros.* 1959, **7**, May 173–177) Action due to vegetation, animal life and bacteria is examined.

Flow of electrolyte within a propagating stress-corrosion crack J. M. West (*Nature*, 1960, **185**, Jan. 9, 92–93) Two simplified crack models constructed of polymethyl methacrylate are described and in presence of a wetting agent measurable effects were obtained with a probe electrode. A diagram of the mode of flow observed with a dye solution is given. The cracking of 18–8 steel is referred to.

Plant site, layout minimize corrosion R. B. Mears (*Chem. Eng.* 1960, **67**, Jan. 11, 144, 146, 148, 150) Climatic and similar factors in plant location are discussed.

Sponginess as a special case of the corrosion of cast iron A. Königer (*Giesserei*, 1960, **47**, March 10, 117–120) The author discusses a rare type of corrosion of cast iron, so-called sponginess. In fact, as he points out, sponginess is not a special type of corrosion at all, it occurs whenever there is a deficiency in O_2 as often happens in buried structures. If there is a lack of O_2 then all ferrous materials show this type of corrosion. The author recommends avoidance of this term.—T.G.

Metallurgical evaluation of superheater-tube alloys after six months' exposure at temperatures of 1100–1500°F C. L. Clark, J. J. B. Rutherford, A. B. Wilder, and M. A. Cordovi (*Trans. ASME J. Eng. Power*, 1960, **82**, Jan., 35–67) The present paper deals with the metallurgical aspects of this programme conducted by the ASME Research Committee on high-temp. steam generation. The results of this examination may be summed up as: Ferritic steels show slight attacks only decreasing with increasing Cr content. Austenitic steels show an appreciable attack particularly on the inside, i.e. by the steam. The mechanical properties of the ferritic steels changed very little, but some of the austenitic steels showed a marked decrease in the room-temp. ductility and impact properties. The austenitic tubes that have failed all showed a marked nitrogen pick-up.—T.G.

Metallurgical progress and the steam engineer L. Sanderson (*Steam Eng.*, 1960, **29**, Jan., 111–113) Causes of corrosion in heat exchangers and plug compositions for stopping leaks, magnetostriction processes in the welding of thin sheets to heavy sections, the use of the new ultra-strength steels and other steels, non-ferrous metals, and fabrication processes are referred to. More information is offered on application.

The corrosion of tinplate containers in the food-canning industry H. Cheftel (*Corros. Anticorros.*, 1959, **7**, April, 125–133) Corrosion due to the existence of an Fe–Sn couple is examined, and it is shown that rate of tinning and porosity of the coating are secondary factors; the important factors are the type of steel, the presence of cathodic depolarizers, an storage temperature (34 refs).

Corrosion of stainless alloys in high temperature nitrogenous environments D. L. Keller [Ed.] (*BMI-1361*, 1959, July 14, pp.50; from *Nucl. Sci. Abs.*, 1959, **13**, Nov. 15, 2579) The effects of the following variables on the behaviour of AISI type 318 stainless steel in N_2 atmospheres was investigated with temp., gas pressure, specimen stress and grain size, time, additions of O_2 and H_2O to the N_2. At atmospheric pressure, oxidation rate was a minimum with 0·5%O_2. Unstressed and stressed specimens were attacked at about the same rate.

Interim report of corrosion by alkali-metal fluorides: Work to May 1, 1953 G. M. Adamson, R. S. Crouse, and W. D. Manly (*ORNL-2337*, 1959, June, pp.36; from *Nucl. Sci. Abs.*, 1959, **13**, Sept. 15, 2022) Various metals were tested for reactor systems, some 316 steels would appear to be suitable.

Corrosion forum: tankers: stainless to plastic gamut R. B. Norden (*Chem. Eng.*, 1960, **67**, Jan. 25, 130, 132, 134) Transport in road vehicles of liquid chemicals is surveyed.

Constitution, metallurgy, and oxidation resistance of iron–chromium–aluminium alloys W. Chubb, S. Alfant, A. A. Bauer, E. J. Jablonowski, F. R. Shober, and R. F. Dickerson

(*BMI*–1298, 1958, Oct. 16, pp.105; from *Nucl. Sci. Abs.*, 1959, **13,** March 15, 389) Limits of the sigma and other phase regions are determined. Methods of fabrication, the deformation processes, and oxidation resistances are also given.

Study of the dry oxidation of iron and steel L. de Brouckere and M. Mathys-Solvel (*Association Belge pour l'Etude, L'Essai et l'Emploi des materiaux (ABEM); joint meeting of the Corrosion Group and Commission No.*IV, 2–3 June, 1954; pp.19) The dry oxidation of iron and mild steel in pure air between 200–900°C with a heating period of 5 min–2 h was examined, and the results obtained are consistent with Vernon's views on the mechanism of the dry oxidation of iron. A semi-quantitative method of detecting magnetite in the presence of Fe_2O_3 is described.

A contribution to the kinetic study of the oxidation of iron at high temperatures and under low oxygen pressures P. Belin (*Corros. Anticorros.*, 1959, **7,** Nov., 384–392) After analysis of different diagrams in the two spheres of oxidation (formation of FeO and conversion to Fe_3O_4) the evolution of oxidation in general is presented as being ruled by a parabolic law except at the very beginning and in the final period of the reaction.—S.H.–S.

Oxidation of high-temperature steels: Effect of alkali sulphate deposits in the presence of sulphur (VI) oxide traces from the furnace gases A. Rahmel (*Arch. Eisenhüt.*, 1960, **31,** Jan., 59–65) Experiments carried out on 12 high-temperature steels showed that deposits of K_2SO_4 on the surface of these steels causes the corrosion rate to increase above 625°C of SO_3 vapours were present. The reaction that takes place mainly by the formation of $K_3Fe(SO_4)_3$ and subsequent formation of a eutectic with K_2SO_4 having a melting point of 627°C is discussed. This potassium–iron sulphate is not stable above 800°C, i.e. no liquid eutectics are present above this temp. and this increase in corrosion rate then ceases to exist. The behaviour of the various steels with respect to this type of corrosion which occurs particularly with oil-firing was examined and the results are reported.—T.G.

Growth and scaling of cast iron I. C. H. Hughes (*BCIRA J.*, 1960, **8,** Jan., 7–28) A review of the mechanisms of growth and scaling of cast iron, including spheroidal graphite cast iron, and dealing with phenomena occurring at low and at high temp. is presented (46 refs).—T.G.

Deposition of corrosion products under irradiation: Van de Graaf study (*WAPD–CDACAD*)–446; *OTS*; 1958, Oct., pp.26; from *Nucl. Sci. Abs.*, 1959, **13,** Dec. 15, 2842) Variables involved in the preferential deposition of corrosion products on fuel element surfaces were investigated by Van de Graaf studies.

Oxidation of titanium–iron alloys J. Stringer, M. G. Cowgill, and N. C. Griffiths (*Nature*, 1960, **185,** Jan. 30, 304) The mechanism of oxidation of Ti with 3–4%Fe is described.

Electron diffraction studies on the high temperature oxidation of iron–aluminium alloys T. Nakayama (*Nippon Kinzoku*, 1959, **23,** Jan., 1–10) [In English] Various Fe–Al alloys were examined. Films formed at 700°C contained mainly α–Fe_2O_3 and γ–Al_2O_3, while those at 1000°C contained α–Al_2O_3 or γ–Al_2O_3. The heat resistance of calorized steel arises from the formation of γ–Al_2O_3 below 1000°C. Water-quenching produces γ–Al_2O_3, while furnace cooling produces α–Fe_2O_3 and α–Al_2O_3. Two reactions for producing Al_2O_3 are given, and the mechanisms under various conditions are discussed.—K.E.J.

Unusual crystal growth observed in the high-temperature corrosion of 304 stainless steel and iron E. A. Gulbransen, T. P. Copan, and D. van Rooyen (*NP*–7699, 1957, Sept., pp.19; from *Nucl. Sci. Abs.*, 1959, **13,** Sept. 13, 2178) Electron microscope and diffraction studies of corrosion products from various atmospheres showed fine oxide whiskers grown at 500°C in wet and dry O_2. With stainless steel, whiskers of Cr_2O_3 were grown, at 600°C in atmospheres containing HCl fan-shaped crystals of Cr_2O_3 were formed, pre-straining accelerates their growth. This may be diagnostic of stress corrosion susceptibility.

The influence of the conditions of oxidation on the kinetics of the growth of the layer of arsenic-containing ferrite in carbon steels with arsenic addition I. I. Chaika (*Fiz. Met. Metallov.*, 1959, (3), 418–420) The thickness of the As-containing ferrite increases according to the same laws as that of the diffusion layer on the saturated surface. But in these tests a typical feature of the As layer was established, viz; that, all other conditions being equal, the thickness of the As-containing ferrite layer depends on the initial As content of the steel.

Distribution of chromium in the sulphide scale of iron–chromium alloys A. K. Krasovskaya and P. V. Gel'd (*Fiz. Met. Metallov.*, 1959, (4), 626–627) When the oxidation period is short and the Cr content of the alloy small spinel grains are formed, insulated from each other on a narrow diffusion front which has little effect on the stability of the alloy. With increasing Cr concentrations and the saturation of the little-permeable crust of the internal sulphide layer of the spinel phase, the rate of oxidation of the alloy rapidly decreases, reaching a constant value which depends on the individual properties of $FeCr_2S_4$.

Electron diffraction studies of crystal structure of oxides of iron A. Pande (*J. Sci. Ind. Res.*, 1958, **17B,** June, 205–208).

Reducing scale formation in turbine condensers by magnetic treatment of the cooling water N. P. Lapotyshkina (*Teploenergetika*, 1959, (11), 45–47) Under operating conditions of steam turbine condensers with cooling water, it was possible experimentally to reduce the intensity of carbonate scale formation by about 80% by first passing the fluid through a magnetic apparatus. It is necessary to investigate further the practical possibilities of this method of water treatment and the mechanism of the action of the magnetic field on the scale formation properties of the original water.

Iron corrosion study National Bureau of Standards (*BNS Techn. News Bull.*, 1959, **43,** Nov., 208) Work on high purity Fe single crystals is referred to.

Fifteen years of atmospheric corrosion trials in Belgium: results of work carried out by Commission IV of A.B.E.M. M. D. Bermane (*Association Belge pour l'Etude, l'Essai et l'Emploi des Materiaux (ABEM); Report of the 234th Meeting of ABEM, March 25, 1953, at Brussels;* from *Ind. Chim. Belge*, **19,** 231–250; pp.22) Results obtained in the period in question are reviewed. The influence of various factors affecting durability and effectiveness of protective paints is examined, and the main protective measures against the corrosion of steel are discussed (21 refs).

Steels resistant to seawater M. Thivin (*Corros. Anticorros.*, 1959, **7,** May, 195–202) Trials are described in which the resistance to corrosion was measured of materials to be used in a tidal motor installation, parallel tests being carried out on a reduced scale model.

Accelerated corrosion testing in the salt spray chamber and other short-time testing methods for protective metal coatings E. Snekvik (*Tek. Ukeblad*, 1960, **107,** Feb. 4, 95–98) The development of the method is outlined, and modifications are described which give reproducible values in a short time.

The corrosion resistance of some stainless steels alloyed with cobalt D. Coutsouradis (*Cobalt*, 1959, Dec., 3–14) Thirteen experimental steels prepared from pure materials were used. Tests in acids and polarization curves were evaluated and the results are shown in tables. The effect of Co was generally favourable.

Effect of mean stress on corrosion-fatigue strength K. Iwamoto (*Trans. Nat. Res. Inst. Met. Tokyo*, 1959, **1,** (1), 73) A brief abstract of a Japanese report. 0·15%C steel was tested under repeated torsional stresses in air and in fresh water at several mean stresses, and an endurance limit diagram plotted.

Effect of differential aeration and of pH on the corrosion of stainless steel in narrow crevices I. B. Ulanovskii and Yu. N. Korovin (*Zhur. Fiz. Khim.*, 1959, **33,** (6), 1414–1417) A fall in O_2 concentration in a crevice will always activate a stainless steel surface but at normal pH values the current quickly falls owing to passivation of the anode. The pH largely controls the intensity of crevice corrosion. A low pH will lead to intensive destruction of the metal in the crevice in some cases.

Some techniques of corrosion testing in molten materials W. M. Spurgeon, C. H. Phillco and B. A. Thompson (*Ind. Eng. Chem.*, 1960, **52,** Jan., 89A–91A) Tests with and without loading and with stationary or moving liquids are outlined, primarily for gas-turbine materials in molten boric oxide.

Loop testing of type 304 stainless steel miniature heat exchangers A. Wiegel and J. W. McGrew (*MND–E*–1696; *AD*–210950, 1959, Jan., pp.37; from *Nucl. Sci. Abs.*, 1959, **13,** Dec. 15, 2837) Examination of three miniature heat exchangers, two of which failed after exposure to corrosive water conditions in a high pressure water loop, showed stress corrosion cracking in the submerged portions of tubes and tube sheets in the exchangers which failed. Failures were all due to transgranular stress corrosion cracking.

HRE–2 corrosion specimens—blanket region of pressure vessels (loading No.1)—weight data and scale analysis A. R. Olsen (*CF*–58–10–83, 1958, Oct. 31, pp.13; from *Nucl. Sci. Abs.*, 1959, **13,** March 15, 389) Type 347 stainless and Zr and Ti alloys corrosion tests are reported.

Loop testing of stainless steel and bimetallic model heat exchangers ERDL Martin Co. (*MND–E*–2092; 1959, July, pp.92; from *Nucl. Sci. Abs.*, 1959, **13,** Dec. 15, 2837–2838) The two model units examined consisted of a steam generator and a super-heater, and these were tested dynamically with selected secondary water conditions in a high-pressure water loop. One set was of stainless steel, and the other of bimetal construction, with stainless steel primary and low-C steel secondary. Considerable general corrosion and pitting were found in the low-C secondary systems of the steam generator and superheater, and cracking of the tube sheet and shell adjacent to the tube sheet caused failure of the type 304 stainless steel generator.

The influence of welding on the corrosion resistance of 18/13/1 steel. Effect of pressure welding H. N. Jones (*RDB(C)/TN*–47, 1953, July, pp.16; from *Nucl. Sci. Abs.*, 1959, **13,** Oct. 15, 2282) Tests in 70%HNO_3 are reported. Susceptibility is due to heat cycling and not to the chemical nature of the heating gases.

Comparative investigation of corrosion resistance of 1H13, H17, H17T, H25T and 1H18N9T steels in water with small chloride contents J. Sedzimir and Z. Zembura (*Hutnik* 1959, **26,** (12), 473–475) The purpose of this work is to investigate the corrosion properties of several chrome steels in order to use them to replace chrome–nickel steels used in the final stages of the manufacture of artificial fibre where the steels operate under wet conditions. The data, given in the graphs, indicate that they are all resistant to corrosion when the water contains less than 70 mg of chloride ions per litre. In the 1H13 steel, corrosion increases with time. Of the five steels, H25T was found to be the best from the corrosion aspect.

Corrosion tests with experimental chrome-pigmented jointing compounds E. G. Savage and H. G. Cole (*J. Appl. Chem.*, 1959, **9,** Dec., 680–684) The effect of sea water spray tests upon a variety of experimental jointing compounds has shown that a compound giving protection appreciably greater than the standard DTD369A can be formulated from a slightly soluble chromate, and a high degree of protection obtained in conjunction with water-resistant self-adhesive tapes.—S.H.–S.

The study of corrosion of pipes under pressure and possible means of protection C. Tschappat (*Corros. Anticorros.*, 1959, **7,** Nov., 393–403; from *Werkstoffe Korr.*, 1958, **9,** (10), 613–623).

Corrosion of zirconium, carbon steel, and stainless steel in high temperature water R. J. Lahsinger (*HW*–56995, 1958, Aug. 6, pp.11; from *Nucl. Sci. Abs.*, 1959, **13,** Nov. 15, 2581) Corrosion data obtained on Zr, carbon steel, and stainless steel exposed to high temp. water at pH7–10 are reported. Tests were conducted to support existing data and to determine the important variables in each system.—D.L.C.P.

Corrosion of stainless steels in fuming nitric

acid M. L.-J. Bernard (*Corros. Anticorros.* 1959 **7,** Nov. 373–383) The resistance to corrosion of 22 grades of stainless steel is statistically described.—S.H.–S.

The influence of contaminating ions on the corrosion of austenitic chromium–nickel steels in nitric acid. A review of progress to 1/9/52 H. N. Jones (*RDB(C)/TN*–15, 1952, Nov. 7, pp.7; from *Nucl. Sci. Abs.*, 1959, **13,** Nov.15) An investigation is described on the accelerating effect of chromate ions on the corrosion of 18/13/1 steel in boiling 70%NHO_3. The following also accelerate corrosion: vanadate, permanganate, and molybdate anions and the ceric cation. The work is continuing.—D.L.C.P.

The ohmic resistance of inhibitor films in the acid corrosion of iron W. Machu and H. I. Morcos (*Werks. Korros.*, 1960, **11,** Feb., 81–87) Direct resistance measurements of organic inhibitors in HCl and H_2SO_4 gave values between 1 and 1200 ohms, results being influenced by the iron surface. High film resistance corresponds to a high inhibiting action and vice versa (22 refs).

Report of preliminary stress-corrosion cracking tests of type-347 stainless steel capsules containing sodium hydroxide G. E. Galonian and H. L. Tymchyn (*KAPL–M–GEG*–12, 1959, June 18, pp.25; from *Nucl. Sci. Abs.*, 1959, **13,** Oct. 31, 2431) Results are reported of stress corrosion cracking tests of type-347 stainless steel. Tests were conducted at 636°F for periods up to 1800 h with M- and 4-M NaOH. All eight capsules not stress-relieved after welding failed in the weld regions by transgranular cracking in 100 h. Two out of four with stress-relieved welds failed in a thin wall gauge section at a stress level of about 22000 psi. Corrosion in specimens exposed for 1425 h was predominantly intergranular. One out of eight U-bend specimens (not stress relieved) failed.—D.L.C.P.

Electron microscope investigation of the structure of metal corrosion layers and adhesive deposits G. Pfefferkorn (**Vereinigung der Grosskosselbesitzer, Mitt.*, 1958, **57,** Dec., 375–381) Examination of the black velvety deposit formed on boiler tube showed this to consist of oxide with acicular or lamellar structure. The needles were shown to grow from the tips, and growth was shown to be a function of oxidation temp. Physical and chemical properties of the deposits are discussed (14 refs).

Method for investigating corrosion and electro-chemical properties of metals under stresses N. D. Tomashov and N. I. Isaev (*Zavods. Lab.*, 1959, (6), 700–702) The phase-oxidized layer on the surface of metals is in many cases a layer with quite a large electrical resistance. This depends on the origin and physical properties of the layer. When the specimen is loaded the film is damaged and this is expressed in changes in the electrical resistance and by the magnitude of these changes it is possible to assess the degree of destruction of the oxidized film. This principle is the basis for the method of analysis described.

The influence of oxygen on the electro-chemical behaviour of stainless steels in sulphuric acid solution P. Berge (*Compt. Rend.* 1959, **249,** July 15, 262–264) It is calculated from an examination of depolarization curves of 18–8 steel in deaerated H_2SO_4, that the rapid depassivation observed is due to a reduction of the passivating layer, and not to the liberation of previously absorbed oxygen.

Effect of pH on electrode potential of stainless steel Yu. M. Korovin and I. B. Ulanovskii (*Zhurn. Prikl. Khim.*, 1960, (1), 167–172) By reducing the pH the electrode potential of many stainless steels is displaced sharply towards the negative. Corresponding to the chemical composition it is possible to reduce appreciably one of the principal causes of failure in confined spaces, the displacement of the electrode potential to the negative side. A reduction of the salinity of sea water from 18·5% does not reduce the dangerous shift of the electrode potential of the steel towards the negative.

Observations made in seawater on test pieces or metal parts coated with zinc by metallising J. Cauchetier (*Corros. Antikorros.*, 1959, **7,** June, 261–264) It is shown that Zn-coated parts, with or without additional treatment, can show good resistance to the action of seawater, but that certain precautions must be taken when parts are exposed alternately to air and seawater.

Directional work-hardening as a means of increasing the corrosion-fatigue strength of pump piston rods R. A. Bagramov and R. M. Raskin (*Vestnik Mashin*, 1959, (10), 9–13) Strengthening pump piston rods by directional work hardening is effected directly by plastic elongation for 6–8% of their initial length and increases the corrosion fatigue strength of 40U steel from 8 to 9·5 kg/mm² and of piston rods of 20KhN steel from 6·5 to 9·5 kg/mm².

Investigating the causes for the corrosion of benzol towers and the methods for reducing and preventing this corrosion A. I. Brodovich, E. I. Gromov, R. V. Krasnovskaya, M. I. Lyukimson, N. M. Dankova, S. A. Velichko, A. A. Belukha, and I. S. Sidorenko (*Koks i Khimii*, 1959, (11), 48–53) Investigations have shown that the corrosion of benzol towers is due to the chemically active components in the coke-oven gas: H_2S, NH_4Cl, NH_4CNS, cyanides, and other components. Some materials have been tested for the construction of new towers and the results are listed.

Investigating new methods for anticorrosion protection for spare equipment D. Ya. Kagan and T. A. Kaganer (*Teploenergetika*, 1960, (1), 55–58) With emulsions containing up to 200 mg/l of octadecylamine or dioctadecylamine or their derivatives the rate of corrosion of steel is reduced by 30–50%. In hydrazine solutions steel practically does not corrode at room temp. For protection coatings for boilers working at high and extra high pressures an ammonia solution with a concentration of at least 500 mg/l of NH_3 or a hydrazine solution in a concentration of 200–300 mg/l N_2H_4 are recommended.

Studies of the corrosion of AISI304 stainless steel and AISI4135 carbon steel exposed to saturated solutions of boric acid C. R. Bergen and D. D. Whyte (Editors) (*YAEC*–67, 1958, Nov., pp.18; from *Nucl. Sci. Abs.*, 2959, **13,** March 15, 394) The stainless steels were not attacked after four weeks.

Investigation of Fe Mn Cr N C system for heat resistance and oxidation resistance between 1200 F and 2000 F J. P. Tarwater and E. J. Dulis (*WADC–TR–57–242*, Part II, 1958, Sept., pp.114; *AD–203523*; from *Nucl. Sci. Abs.*, 1959, **13,** March 15, 393) Steels containing V, Nb, W, and/or Mo were used and ductility and creep rupture properties were improved with decrease of impact properties. Ca and Si additions were also made.

The effect of chloride on the corrosion of austenitic steel in nitric acid T. E. Evans and P. A. Hayes (*RDB(C)TN*–124, 1955, April, pp.9; from *Nucl. Sci. Abs.*, 1959, **13,** March 15, 392) Corrosion is increased in the vapour phase but not appreciably in the liquid phase. This may be due to increased concentration in condensate.

The effect of ionizing radiation on the corrosion of metals under atmospheric conditions A. B. Byalobzheskii (*Zhur. Fiz. Khim.*, 1959, **33,** (6), 1256–1262) The corrosion of Fe and other metals in a moist atmosphere is shown to be greatly accelerated by electrons, X- and γ-rays at intensities producing absorption of not less than 10^{14} eV/l air. This is due to the formation of O_3, H_2O_2, N_2O_5, and especially to transient HO_2, OH, NO_3, etc. N_2 becomes an active corrosion agent owing to HNO_3 formation.

The mechanism of anodic inhibitors of corrosion: a general treatment T. P. Hoar (*Association Belge pour l'Etude, l'Essai et l'Emploi des Materiaux* (*ABEM*); joint meeting of the Corrosion Group and Commission No.IV; 2–3 June 1954, pp.12) [In English] Various theories of anodic corrosion inhibition are reviewed, and the possibility of combining them in a comprehensive theory is examined. It is suggested that the anodic process can be hindered by several kinds of blocking, of which more than one kind may occur simultaneously, and the joint action of two or more inhibitors in specific cases is discussed (58 refs).

Tensammetric studies on corrosion inhibitors. I. Dicyclohexylamine nitrite K. S. Rajagopalan, V. K. Venkatesan, and K. Balakrishnan (*Proc. Indian Acad. Sci.*, 1959, **50A,** Oct., 272–281) Tensammetry is an ac polarographic process. It is applied to the adsorption of the inhibitor and compared with potential measurements and direct corrosion tests.

Corrosion inhibitors for cast iron and other metals in ethylene glycol solutions and in mains water A. D. Mercer and F. Wormwell (*J. Appl. Chem.*, 1959, **9,** Nov., 577–588) The use of ethylene glycol solutions and various admixtures as inhibitors for cast iron corrosion is examined, and the reduced rate of corrosion in ethylene glycol solutions without inhibitors is discussed. Electrode-potential/time curves obtained from various metals in ethylene glycol solutions reflect their corrosion behaviour.—S.H.–S.

Anti-fouling and corrosion prevention combined in new system F. A. Hughes and Co. Ltd (*Corros. Techn.*, 1959, **6,** Dec., 364–365) The system known as Toxion, and for which a patent application has been made consists in discharging a highly toxic but non-persistent poison by compressed air through plastic pipes on to a ship's hull and applying the current which gives cathodic protection, thus causing the poison in the form of bubbles to be attracted to the hull. A trial has given satisfactory results.

Protection of a ship's water-tube boilers against corrosion I. L. Andreyev and A. I. Lukovkin (Trans. from *Zaschita Sudovykh Vodotrubykh Kotlov ot Korrozii*, 1958; *NRL Trans. No.* 740; 59–21090, pp.3; contents only; from *US Dept. Commerce Techn. Trans.*, 1959, **2,** Nov. 20, 742).

The permanent anode in impressed-current cathodic protection systems—Part I C. A. Curtis (*Corros. Techn.*, 1959, **6,** Oct., 296–298 The properties, uses, and limitations of graphite, silicon iron (4%Si, 3%Mo), and scrap steel as anodes are discussed.

Corrosion inhibitors for ethylene glycol solutions, with particular reference to cadmium-plated and terne-plated steel A. D. Mercer and D. M. Brasher (*J. Appl. Chem.*, 1959, **9,** Nov., 589–594) Cadmium-plated steel, terne-plated steel, and tin-plated copper are effectively protected in ethylene glycol solutions containing sodium benzoate and sodium nitrite, and also in DTD779.—S.H.–S.

Influence of inhibitors on the corrosion of iron H. Grubitsch and T. Sneck (*Corros. Anticorros.*, 1959, **7,** April, 153–161) The influence of hexamethylenetetramine and quinoline ethiodide on the corrosion inhibition of iron in acid and neutral electrolytes was investigated on O_2-depolarized cells. Hexamine behaves as an anodic inhibitor in neutral, and as a cathodic inhibitor in acid solutions. The quaternary salt has very little effect in neutral solution, but is a very powerful anodic inhibitor, and to a much smaller extent a cathodic inhibitor in acid electrolytes.

Electric current ends process corrosion R. B. Norden (*Chem. Eng.*, 1959, **66,** Nov. 30, 112, 114, 116) Controllers protecting a sulphonate plant by anodic passivation are described.

Development work in the field of corrosion protection and scaling W. Kirsch (*Forsch. Wirts. Nordrhein Westfalen*, 1957, (406), pp.76) Subjects dealt with include—theories of corrosion mechanism and methods of protection, with special reference to recent improvements and developments. These include the use of plastics and protection against microbiological action; with particular reference to applications to pipes for carrying oil, water, and gas. The bibliography includes patent specification references (26 refs).

Protection of metal structures against corrosion M. van Rysselberge (*Publ. of Commission from l'Etude de la Protection centre la Corrosion, ABEM*, 1959, pp.40) Causes of metal corrosion are reviewed, and various protective measures discussed, including various types of coatings and paints and their testing.

Protection of steel structures against rust in the chemical industry G. Sille and O. Damm (*Technik*, 1959, **14,** July, 469–471) A general review of paint systems and their testing (13 refs).

Calculation of sacrificial protection. I. The process determining the rate of the electrochemical reaction P. P. Doganadze, V. G. Levich, and Yu. A. Chizmadzhev (*Zhur. Fiz. Khim.*, 1959, **33,** (5), 1111–1118) The potential

distribution over the surface of a metal protected in a planar system is calculated and is in reasonable agreement only at large distances compared with the width. A model is proposed for the region near the protector.

Corrosion protection at the ship hydrodynamics laboratory (*Corros. Techn.*, 1960, **7**, Jan., 23–24) The solutions of various corrosion problems connected with the facilities at this laboratory are described.

The tanker anode–safety considerations in design (*Corros. Techn.*, 1960, **7**, Jan., 21–22) Problems of Mg anode manufacture mounting and system design from the safety point of view are considered.

Advances in cathodic protection of tankers D. Spector (*Corros. Techn.*, 1960, **7**, Jan., 5–8) Details are given of the installation of an anode system between constructional members of the ship.

Further experiments on the prevention of pitting attack on cast iron propellers by cathodic protection R. I. Higgins and H. H. Collins (*BCIRA J.*, 1960, **8**, Jan., 39–66) Details of tests on the effectiveness of various types of Mg anodes fixed to the propeller itself and to the hull are reported. The conditions under which the anode may be attached to the hull are described. In no case studied was full protection obtained, but it is suggested that a heavy-duty coating of the propeller will be beneficial. Details of ships and performance of cathodic protection are included.—T.G.

ANALYSIS

Some recent developments and current problems in metal analysis R. M. Fowler (*Anal. Chem.*, 1959, **31**, Dec., 1949–1951) The determination of C in steel is reviewed over the last 40 years.

Amperometric titrations W. M. Smit (*Chem. Weekb.*, 1960, **56**, Jan. 14, 25–39) Amperometric titrations may be conducted with an indicator electrode in combination with a reference electrode, or by means of two indicator electrodes. With the help of assumptions, the paper develops formulae indicating the connexion between current strength and concentration for reversible and irreversible redox systems. With the help of the formulae, views are put forward regarding the voltages preferred and the means available to ensure the accuracy of the titration. Two examples are given, namely the titration of uranium with permanganate in the presence of excess iron and also that of calcium with fluoride.

Coulometric titrations E. Barendrecht (*Chem. Weekb.*, 1960, **56**, Jan. 23, 37–48) This paper describes what is understood by coulometry and goes on to indicate the general possibilities of using the method under conditions of constant potential and current for titrating. Some examples are put forward with illustrations and emphasis being laid on the suitability of the method for carrying out micro-analyses, determinations of traces, and for automatic titrations. There is also reference to the titration of carbon in steel. The paper concludes with an extensive bibliography (66 refs).

Relationships between metal complex stability and the structure of the complexing agents G. Schwarzenbach (*Anal. Chem.*, 1960, **32**, Jan., 6–9) Complexing agents are classified and co-ordination tendencies are compared.

Synthesis of 2-(2-hydroxy-5-methoxybenzeneazo)-4-methylthiazole and its colour reactions with metallic ions T. Yanagihara, N. Matano, and A. Kawase (*Trans. Nat. Res. Inst. Met. Tokyo*, 1959, **1**, (1), 65–68) The colour reactions of this dyestuff with a number of ions are examined. A violet chelate having maximum absorption at 391, 554, and 777 mμ is obtained with Fe^{3+}, this is suitable for determination of γ quantities.

Sulphur printing—a new evaluation S. Ramachandran and W. G. Renshaw (*Met Prog.*, 1959, **76**, July, 101–104) Sulphur printing is essentially a corrosion phenomenon, and misleading results may be obtained as a result of small currents developed between inclusions and the base metal. The results must be interpreted along with those from other tests.

The determination of carbon in Cr_3C V. Dufek and Z. Marek (*Hutn. Listy*, 1959, **14**, (10), 909–912) Optimum conditions for the analysis of chromium carbides, i.e. for free and combined carbon, were determined in a series of experiments. The CO_2 formed, by oxidation of the carbides in O_2 at temperatures up to 1450°C, was determined gravimetrically after absorption in NaOH.—P.F.

Vacuum determination of hydrogen in steel N. G. Banerjee (*NML Techn. J.*, 1959, **1**, Aug., 17–21) Apparatus is described giving reliable results even with as little as 0·1 ml/100 g.

Further information on sampling liquid steel for dissolved oxygen F. C. Langenberg and J. M. Snook (*Trans. Met. Soc. AIME*, 1959, **215**, Aug., 706–707) Four modifications of the conventional bomb sampler for determining oxygen in liquid steel have been investigated. All gave reliable results, but two methods are recommended for practical reasons.—A.G.

Determination of oxygen in cast iron H. Goto, S. Suzuki, J. Kimura, and A. Onuma (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1959, **11**, (4), 271–275) [In English] The analysis requires total oxygen and oxygen in each oxide. The fractional vac. fusion method, using a tin bath, enabled FeO to be extracted at 1050°, MnO at 1150°, SiO_2 at 1450°, and Al_2O_3 at 1750°C, but TiO_2 could not be extracted separately. This method and the chlorine method give good results, compared with the non-metallic inclusions method.—K.E.J.

Extractive determination of iron and cobalt in the presence of nickel S. E. Kreimer and L. P. Butylkin (*Zavods. Lab.*, 1959, (6), 662–666) Bisantipyrinylmethane gives sparingly soluble compounds with thiocyanides of Fe, Co, Cu, and other metals and does not give precipitates with Ni. The methods described are all based on this fact.

The electrometric determination of dissolved oxygen in aqueous solution G. S. James and M. J. Stephen (*Analyst*, 1960, **85**, Jan., 35–39) An error of <2% was observed at the lowest conc. used, 0·03 ppm O_2.

Heterometric micro-determination of traces of iron in thiocyanate solutions by titration with nitron M. Bobtelsky and A. H. I. Ben-Bassat (*Anal. Chim. Acta.*, 1959, **21**, Nov., 411–415).

Methods of determining hydrogen in relation to chemical composition and structure of steel Yu. A. Klyachko and T. A. Izmanova (*Zavods. Lab.*, 1959, (4), 396–398) Heating *in vacuo* for determining H_2 in steels containing up to 0·5%C, and melting *in vacuo* for higher carbon contents are made use of in this determination. Cr steels can also be analyzed for H_2 by heating *in vacuo*; below 0·05%C. Ti and Mn steels are analyzed for H_2 by melting *in vacuo* and niobium, Ni and Al steels in any proportion are analyzed for H_2 by heating *in vacuo*.

Critical study of the determination of hydrogen in steel J. Calmettes, C. Dubois, and P. Bastien (*Rev. Mét. Mém. Sci.*, 1959, **56**, Dec., 641–656) Standardization of sampling conditions is discussed, and a new apparatus is described, equipped with a Pd filter for separating H_2 during the degassing of a steel sample held *in vacuo* at constant temperature. Under these conditions, at 600°C, evolution of H_2 follows an exponential law. By the technique described, a determination sufficiently accurate for routine control can be made and reported in less than 30 min. from sampling.

Elimination of cobalt from manganese by nitroso-R-salt with Ionite L. M. Orlova (*Zavods. Lab.*, 1959, (4), 417).

Determination of trace amounts of cobalt in steel by 2-nitroso-1-naphthol K. Hosoda (*Tetsu to Hagane*, 1959, **45**, March, 295–297) Results are discussed for determinations on 18–8 and 19–9 steels, carbon steel, ingot iron, and electrolytic iron.—K.E.J.

Photo-colorimetric analysis of niobium in carbide mixtures R. M. Veitsman (*Zavods. Lab.*, 1959, (5), 552–554) A method is described permitting determination of Nb in the presence of Ti, Ta, W, and all components of complex carbides. W (up to 70%) is eliminated as phosphate complex. Ti forms complex phospho-molybdo-Ti heteropolyacids. Nb (0·1 g of specimen) is dissolved in 20 ml H_2SO_4 (1:4); 7·5 ml of 10% $(NH_4)_2HPO_4$ solution and 1 g H_3BO_3 are added, mixed with 10 ml of 4% Trilon B solution, diluted to ~130 ml and 10 ml of 10%NH_4 molybdate are added and heated to 30–35°.

A simple procedure for vacuum chlorine separation W. Koch and O. Gautsch (*Arch. Eisenh.*, 1959, **30**, Dec., 723–730) In order to simplify the vacuum Cl separation of electrolytically isolated steel residues, the halogen and the mixture of phases were introduced to different parts of a glass tube, and by adjusting temp. and pressure the most suitable reaction conditions could be obtained, Br_2, I_2, and halogen compounds and solutions were also used (18 refs).

Trilon B in the determination of chromium in steel M. E. Vdovenko and N. E. Spivakovskaya (*Zavods. Lab.*, 1959, (4), 416–417) Since at a pH of 1·5–2·0 dichromate is still being reduced by KI (3–5 min.) and the vanadate interacts with it rather slowly, a method of Cr determination is suggested for steels with or without V, even in the presence of W. Some standard specimens containing V, W, and Ni as well as Cr have been analyzed for Cr by this method and the results obtained agreed with the standards within very narrow limits.

Photometric determination of vanadium in steels A. I. Cherkesov and T. S. Zhigalkina (*Zavods. Lab.*, 1959, (4), 406–408) The method proposed is based on the oxidation of certain azo-dyes by vanadate in H_2SO_4. Two dyes synthesized on the basis of sulphanilic and naphthionic acids by coupling with 2·3-oxynaphthoic acid are suggested. The reaction is explained and the results show a very close correspondence.

Spectrophotometric determination of titanium with 9-methyl-2:3:7-trihydroxy-6-fluorone A. K. Majumdar and C. P. Savariar (*Anal. Chim. Acta*, 1959, **21**, Dec., 584–587).

The direct reading spectrograph at the Monlevade plant of CBSM H. V. Ligten, C. Costa, and J. Wscieklica (*Bol. ABM*, 1959, **15**, Oct., 745–756) [In Portuguese] An ARL quantometer has been installed and a description of it and its programme is given.—P.S.

Experiences with direct-reading spectrographs in the iron and steel laboratory. 11th report T.–K. Willmer and W. Liedtke (*Arch. Eisenh.*, 1959, **30**, Dec., 713–714) The use of a spectrometer in a steelworks of Bochumer Verein is described. Bath and pit samples are analysed from LD plant, and open-hearth and electric furnaces. **12th report and discussion** J. Bruch (715–721) Sample preparation and bath and pit sample analysis of steels at Gussstahlwerk Witten are described. Accuracy of low- and high-alloy steels was comparable with that obtained by wet chemical analysis.

A new possibility of using the IG-2 generator for the spectrographic analyses of high alloy steels and welded joints A. S. Dem'yanchuk, V. M. Plotnitskii, and O. P. Ryabushko (*Avtom Svarka*, 1959, (4), 89–91) The apparatus is described with a block diagram of its operation and specimens of calibration graphs are shown, e.g. for determining high nickel contents up to 35%.

Determination of carbon in steels by means of the styloscope A. S. Dem'yanchuk (*Avtom. Svarka*, 1958, (11), 37–39) Spectrochemical analysis is described using spectral lines C II 6578·03 and C II 6582·85A in the red and Styloscope type SL–3 with a low voltage generator. A copper electrode can determine 0·05%C. Photometric estimations of carbon content from traces to 1·5% are tabulated.

Spectrophotometric analyses of isolated carbides J. Jánošík and M. Kovařík (*Sborník, (Ostrava)*, 1959, **5**, (4), 491–496) A method for the spectrophotometric determination of Fe, Mn, Cr, Mo, V, and Ti in carbides isolated from steels has been developed. A few Mg of sample are sufficient; the accuracy is greater than that attainable by chemical means. The Czechoslovak spectrophotometer SF–4 was used in the work.—P.F.

Regarding a special feature of the spectrochemical determination of carbon and phosphorus in steel and welded joints E. S. Kudelya (*Avtom. Svarka*, 1959, (3), 59–63) Experiments have shown that with exactly the same conditions of excitation and photographing of the spectra of different alloy mixtures, the corresponding lines used for analysis show absolute blackening differing considerably in the spread of readings and errors. A comparison of results

makes it clear that the determination of carbon and phosphorus by the absolute blackening of their spectral lines is conditioned exclusively by the manner of exposing these elements to the radiation of the cloud discharge.

Simultaneous determination of carbon and alloy elements in steel A. S. Dem'yanchuk (*Zavods. Lab.*, 1959, (5), 581–583) Under the normal conditions of photographing the spectra of C and alloying elements, the bending effect must be eliminated or appreciably reduced. The analysis was carried out by the method of three standards. The calibration curves had a slope of 45–60°. The results were checked on specimens repeatedly analyzed spectrally and chemically and a few results are tabulated.

Determination of boron in iron alloys L. S. Evlashin and L. A. Zatuchnaya (*Zavods. Lab.*, 1959, (5), 580–581) The most satisfactory boron line for spectrochemical use is at 2497·73 A° by which it is possible to detect B down to 0·0001%. On spectrographs of average dispersion this line is not resolved however. Spark generator type IG–Z was used. In the spectra of borax, ferro-boron, and of steel containing down to 0·001%B the line of the doubly ionized B atom, 2065·8 A°, appears, which has good sensitivity and is free from superimposed spectra of most of the elements of alloy steel and iron. The mean square error (comparison line Fe 2063·7 A°) is ±6%, which is less than the error for visual determination from line 2496·78 A°.

Spectrochemical determination of aluminium in chromium–nickel austenitic steels and welded seams E. S. Kudelya (*Avtom. Svarka*, 1959, (6), 28–30) Under the conditions of the experiment Al is determined with a precision of ±4% in concentrations from 0·25–1·8%. The investigation has proved it possible to determine Al in the types of steel examined, from the line Al 3082·155 A°. The accuracy of the determination of Al by the absolute darkening of its analytical line practically equals the accuracy of the analyses by difference in blackening.

Relation between the composition of the solid and gaseous phases in the spectral analysis of alloys on an iron base O. I. Nikitina, M. G. Sklyar, A. E. Gorevaya, and N. K. Ivanova (*Izvest. Akad. Nauk, SSSR, Ser. Fiz.*, 1959, **33**, (9), 1069–1072) The relation was established between the chemical composition of the binary alloys Fe–Cr, Fe–Mn, Fe–Si, Fe–W, Fe–C, and the ternary alloy Fe–Cr–C and their vapours in the discharge. During the investigation the rate of vaporization was also established for the various elements as a function of their concentrations. In small concentrations of alloy elements the weight of iron deposited in unit time increased, the rate of vaporization of iron went through a maximum and then decreased again for any given concentration of an alloy element.

Phenyl-2-pyridyl ketoxime, a reagent for iron in strong alkalis: a method for determining oxidized iron in the presence of metallic iron F. Trusell and H. Diehl (*Anal. Chem.*, 1959, **31**, Dec., 1978–1980) The red complex is extracted with *iso*amyl alcohol.

Determination of silicon by distillation–colorimetric method B. D. Holt (*Anal. Chem.*, 1960, **32**, Jan., 124–128) The method separates microgram quantities of Si as tetrafluoride which is determined as Mo blue complex. It can be used for steel.

Improvements in the photometric determination of silicon Z. Konečný (*Hutn. Listy*, 1959, **14**, (10), 903–904) The stability of the blue silicate–molybdate complex used in the photometry, and other aspects of the analytical procedure were studied and optimum conditions to be maintained for most accurate results were determined.—P. F.

The analysis of non-metallic inclusions in steels H. Bizouard and J. Philibert (*Rev. Mét.*, 1959, **56**, July, 123–124) An account is given of the use of the Castaing microsonde adapted for the determination of light elements, e.g. Na, Mg, Si, P, and S in non-metallic inclusions.

Studies on the microdetermination of metals by extracting the inorganic compounds with organic solvents. III. Microdetermination of molybdenum H. Goto and S. Ikeda (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1959, **11**, (4), 276–284) [In English]. Mo reduced by $SnCl_2$ or N_2H_4, H_2SO_4 forms complex thiocyanate compounds, which can be extracted by acetic esters or alcohols or mixtures of these with $CHCl_3$ or CCl_4. The max. absorption peaks are at 335 and 468 mμ when $SnCl_2$ is used, and 320 and 460 mμ when hydrazine sulphate is used. Optimum conditions for the spectrophotometric determination are given.—K. E. J.

Gravimetric determination of cobalt and nickel and their separations from copper with *N*-benzoylphenylhydroxylamine S. K. Sinha and S. C. Shome (*Anal. chim. Acta*, 1959, **21**, Nov., 459–462) The precipitates are directly weighable.

Volumetric determination of manganese by the method of Lingane and Karplus in cast irons and steels J. F. W. Tertoolen, C. Buijze, and G. J. van Kolmeschate (*Chim. Anal.*, 1960, **42**, Jan., 9–14) The effects of graphite, Cr, Ni, Mo, Sb, V, W, and Co were examined.

Coulometric titration with higher oxidation states of manganese. Electrolytic generation and stability of +3 manganese in sulphuric acid media R. G. Selim and J. J. Lingane (*Anal. Chim. Acta* 1959, **21**, Dec., 536–544) The disproportionation constant is evaluated.

Determination of nickel and cobalt in high-alloy and stainless steels L. L. Lewis and W. A. Straub (*Anal. Chem.*, 1960, **32**, Jan., 96–99) Ni is separated with dimethylglyoxine and Co by ion exchange. They are then determined with (ethylenedinitrilo)tetra-acetic acid.

Separation and determination of titanium in stainless steels M. N. Nadkarni, G. G. Nair, and C. Venkateswarlu (*Anal. Chim. Acta.*, 1959, **21**, Dec., 511–514) A spectrophotometric method is described removing Fe by ether extraction and coprecipitating with Zr as PO_4.

Polarographic determination of titanium in tantalum and niobium concentrates and ores D. K. Banerjee, C. C. Budke, and F. D. Miller (*Anal. Chem.*, 1959, **31**, Nov., 1836–1839) Ta, Nb, Fe, Sn, Mn, and W do not interfere.

The determination of uranium and molybdenum by selective precipitation with 8-hydroxyquinoline L. E. Storms (*GAT*-285, 1959, July 21, pp.13; from *Nucl. Sci. Abs.*, 1959, **13**, Dec. 15, 2803) V is precipitated in the presence of versene from an ammoniacal solution containing Mo, which is then precipitated from the filtrate after adjusting the pH.

Colorimetric method for determination of vanadium employing 1-2-pyridylazo-2-naphthol F. W. Staten and E. W. D. Huffman (*Anal. Chem.*, 1959, **31**, Dec., 2003–2007) The blue complex is measured in $CHCl_3$, a correction for Fe is shown.

Separation of zirconium from titanium, ferric iron, aluminium, and other cations by cation exchange chromatography F. W. E. Strelow (*Anal. Chem.*, 1959, **31**, Dec., 1974–1977) Use of AG 50WX8 resin in HCl separates Zr preferentially.

Study of the polargraphic behaviour of zirconium in acid solution in the presence of nitrate ions P. Mechelynck and C. Mechelynck-David (*Anal. Chim. Acta*, 1959, **21**, Nov., 432–439) [In French] A catalytic wave quantitative for nitrate, is observed.

Determination of zirconium with *N*-benzoylphenylhydroxylamine I. P. Alimarin and Tze Yung Sian (*Zhur. Anal. Khim.*, 1959, (5), 574–577) A new method was evolved for quantitative precipitation of Zr with *N*-benzoylphenylhydroxylamine and the effect of different mineral acids and of tartaric acid and H_2O_2 on the degree of precipitation has been studied. Its precipitation in the presence of other elements has been investigated. Zr can be separated from iron, Al, Cr, Ti, Nb, and Ta and the compositions of the Zr complex corresponds to the formula $Zr(BPHA)_4$.

A study of the simultaneous precipitation of zirconium and tervalent cerium oxalate by means of nascent reagents V. P. Shvedov N. A. Pavlova, and M. I. Bulatov (*Zhurn. Anal. Khim.*, 1959, (5), 571–573) It has been shown that Zr is precipitated together with the tervalent Co oxalate on account of adsorption. The coprecipitation of Zr decreases with increasing acidity of the solution and the Zr adsorption increases with increases in its concentration.

Separation of antimony (V) from iron (III), copper (II), cobalt (II) and cadmium (II) by ion exchange S. S. M. A. Khorasani and M. H. Khundkar (*Anal. Chim. Acta*, 1959, **21**, Nov., 406–410) Sb is complexed with tartaric acid.

Simultaneous determination of copper and tin in carbon and alloy steels by means of a.c. polarography. (Studies on the rapid analysis of iron and steel by means of a.c. polarography). I O. Kammori and M. Ikeda (*Nippon Kinzoku*, 1959, **23**, Feb., 100–104) A routine method taking about 16 min. for the determination of Cu and Sn in carbon and alloy steels is described. From the impurities present only Pb interferes in the quantities usually met within steels.—T. G.

Polarographic determination of micro quantities of copper, lead and zinc in the presence of iron A. A. Sakharov (*Zavods. Lab.*, 1959, (7), 791–792) A method is explained for polarographic determination of Cu, Pb, and Zn in amounts of the order of micrograms in solutions containing large quantities of iron, without its removal. Cu and Pb are determined against a background of ammonium tartrate solution. Pb and Zn against a background of a weak acid or neutral solution containing ascorbic acid. All traces of dissolved O_2 must be carefully removed in view of the high-sensitivity galvanometer used.

The spark test Tardieu (*Centre Doc. Sidér. Circ.*, 1959, **16**, (9), 2047–2054) The theory of the method and its application to the rapid sorting of steel grades in a batch is discussed with examples.

Experiences with direct-reading spectrographs in iron- and steelworks laboratories. 2nd report G. Hartleif and H. Kornfeld (*Arch. Eisenh.*, 1959, **30**, Aug., 485–488) Experience in the analysis of iron and steel specimens at Dortmund-Hörder is reported and discussed. **3rd Report** P. Dickens and A. Bähr (489–491) Experience in the analysis of iron and steel specimens at Duisburg-Huckingen is reported and discussed. **4th Report** V. Mathien, M. Lacomble, and L. Charlet (493–495; 495–496) Experience in the analysis of iron and steel specimens at Cockerill–Ougrée is reported and discussed. **5th Report** A. Brandt and W. Berstermann (Sept., 541–543) Use of the spectrograph at the Georgsmarienhütte works of Klöckner-Werke AG for pig iron and steel analysis is described. **6th Report** H. Manecke and W. Brokopf (Sept. 545–547, discussion 547–548) Analysis of bath and pit samples with the spectrograph at Klöckner-Hütte Bremen AG is reported. **9th Report** G. Wollweber and R. Fehle (Nov., 655–657) The conditions under which special steels, particularly high-Si steels, can be determined with a direct-reading spectrograph are investigated. **10th Report** H. Hildebrand and W. Diehl (659–660) Method of sampling and sample preparation, and conditions of analysis of bath and pit samples of plain C and low-alloy steels using a multi-source unit are described, according to the practice at the Röchling-Buderus steelworks.

Report on the manufacture of a spectroscope for steel analysis Physics Dept. of Nang-Kai Univ. (*Acta Phys. Sin.*, 1959, **15**, June, 277–281) [In Chinese] The instrument, based on the Fuess spectroscope, is an achromatic autocollimating instrument with a special specimen holder and a high-frequency source. The resolving power is 0·14 Å at λ = 4358 Å and 0·59 Å at 5893 Å.—K. E. J.

Determination of cobalt by radiometric titration with potassium ferrocyanide D. I. Eristavi, F. I. Brouchek, and T. A. Tsivtsivadze (*Zhurn. Anal. Khim.*, 1959, (5), 631–633) It has been established by radiometric titration of small concentrations of Co ions with $K_4Fe(CN)$ that the composition of the precipitate corresponds to the formula $K_4Co_3[Fe(CN_6)]_2$. The possibility has been demonstrated of determining small amounts of Co by radiometric titration with $K_4Fe(CN)_6$ with ^{60}Co as indicator.

Rapid determination of the phosphorus content of steel during manufacture by use of the isotope dilution method J. Fodor (*Acta Chim. Acad. Sci. Hungaricae*, 1959, **19**, (1), 13–21; from *Hung. Techn. Abs.*, 1959, **11**, (4), 131) [In English] The isotope ^{32}P is introduced into the metal bath and uniform distribution is attained in 5 min. Samples of the castings can then be analysed for P within 5 min of sampling.

Study on chemical analysis of basic slag. I. Determination of SiO_2, total Fe, Al_2O_3, MnO, CaO and MgO in basic slag S. Wakamatsu (*Tetsu to Hagane*, 1959, **45,** July, 717–722) To arrive at rapid and accurate methods for analysing basic slag, full details are given of a continuous titration method with EDTA for determining total iron, Al_2O_3, MnO, CaO, and MgO (14 refs).—K.E.J.

On basicity and potential of slags. II. A method of measuring the activities of lime in various slags K. Sawamura (*Tetsu to Hagane*, 1959, **45,** March, 238–239) The measurement is derived from observations in the electrolytic cell W–Ca/CaO in slag I/O (graphite)–(graphite) O/CaO in slag II/Ca–W.—K.E.J.

Design of an improved apparatus for the rapid and accurate determination of gases in metals and results obtained with this apparatus H. Feichtinger, H. Bächtold, and W. Schuhknecht (*Schweiz. Arch.*, 1959, **25,** Dec., 426–439) An apparatus is described for determining the gas evolution of metals in relation to both temp. and gas-evolution kinetics. The gas-analytical control of steel heats during processing in the works is explained and illustrated and examples are given of a distinction that can be drawn between labile and stable gas–metal compounds. An attachment to this apparatus also allows the determination of N_2. The new method is very much more rapid than the conventional hot-extraction. Further improvements are expected from combination with gas chromatography.—T.G.

The gas chromatograph used as semi-micro-analyser of gases extracted from metals J. Václavínek (*Hutn. Listy*, 1959, **14,** (10), 905–909) A gas chromatograph, utilizing CO_2 as carrier, was used for the analysis of gases extracted in vacuum melting. CO, N_2, H_2, and other gases are rapidly determined. The equipment is easily handled inexpensive and readily serviced. Results reproduce well, as was shown by several analyses of gases liberated from grey cast irons.—P.F.

INDUSTRIAL USES AND APPLICATIONS

Technical and economic factors of steel construction R. Heckel (*Acier-Stahl-Steel*, 1959, **24,** Dec., 536–537) Costs and economics in weight, etc., are briefly considered.

Research and industrial use of steam boiler steels V. A. Larichev (*Teploenergetika*, 1959, (1), 9–14) A study of a large number of pearlitic and austenitic steels, the latter with Cr and Ni is reported.

The selection of steel for forming plastics with special attention to steels that can be cold-worked J. Jägersberger (*Schweiz. Arch.*, 1959, **25,** Dec., 439–450) The properties of tool steels suitable for dies for plastics are reviewed with special reference to high-strength case-hardening steels. The merits of nitriding steels, particularly their excellent surface quality, are mentioned. The steels must be capable of being cold-pressed, a process that is increasingly used in tool making. The need of standardization of steels for dies for the various types of forming plastics is emphasized.—T.G.

Experience with an ink tank car of stainless steel A. I. Rabinovich (*Koks i Khim.*, 1959, (7), 76) The weight of the tank car is 65 t and all parts coming into contact with phenol are made of stainless steel of which 20 t went into its construction. After six months in service the truck was examined for wear and it was found that all stainless steel parts showed only insignificant corrosion.

How to select stainless steel for use in the mining industry. Part I. Principles of selection R. E. Paret (*Eng. Min. J.*, 1959, **160,** Dec., 106–109) Types of stainless steel and their properties are outlined, and a brief account of methods of material selection is given.

The steel tube, a universal means of conveying fluids and solids M. A. de la Tour (*Mém. Soc. Ing. Civils France*, 1959, **112,** July–Aug., 221–232) Economical and technical aspects of conveyance by steel pipeline are examined, and the use of pipelines for the conveyance of gas, oil, water, and coal is discussed.

Hot-work toolsteel for aircraft P. E. Ruff (*Met. Progr.*, 1959, **75,** March, 103–107) 5%Cr tool steels used for many years for dies have found a new field of application in supersonic aircraft and missiles, at a UTS of up to 300000 psi they resist softening up to 925°F. Impact strength, fatigue strength, and corrosion resistance of this steel is adequate for the purpose.—T.G.

Design information on 5 Cr alloy steels for aircraft and missiles F. R. Morral, R. J. Favor, and W. P. Achbach (*DMIC*–116; *PB*–151072, 1959, Aug., pp.44; from *Nucl. Sci. Abs.*, 1959, **13,** Dec. 15, 2837) Heat treatment, melting practice, corrosion protection, manufacturing problems, and elevated-temp. properties of the 5 Cr–Mo–V (H–11 type) alloy steels are examined in relation to their use in aircraft and missile applications.

Missile metallurgy selection of materials and heat treatment of rocket and missile bodies H. C. Knerr)*Met. Treating*. 1959, **10,** Nov.–Dec., 6–9, 34–36, 38, 44–47) A discussion in practical terms, on selection of materials and on fundamental heat-treating problems for rocket and missile bodies.—S.R.–S.

Metals used in the Vanguard C. Hirst (*Met. Progr.*, 1959, **75,** March, 73–76) For the second-stage propellant tankage, stainless steel type 410 is used as it withstands the corrosion from the second-stage propellant and can be welded and heat-treated. Welding is carried out manually by the inert-gas shielded-W-arc process.—T.G.

Development of iron–aluminium base alloy for gas cooled reactor components F. Tate (*MND–DB*–2525, 1959, April, pp.139; from *Nucl. Sci. Abs.*, 1959, **13,** Sept. 15, 2060) Criteria for the optimum alloy properties are given and work on the development of materials with these properties is described.

Properties of uranium dioxide stainless steel dispersion fuel plates S. J. Paprocki, D. L. Keller, and J. M. Fackelmann (*BMI*–1339, 1959, April, pp.25; from *Nucl. Sci. Abs.*, 1959, **13,** Sept. 15, 2059) Measurements up to 1650°F are reported.

Atomic power plant construction depends on steel (*Esso Oilways*, 1959, **10,** (3), 2–4) Uses at Calder Hall are mentioned.

Survey of steels used in nuclear plant F. Baldi (*Met. Ital.*, 1959, **51,** Nov., 515–520) The requirements are examined of materials used in nuclear plant inside the reactor and within the primary circuit, with particular reference to corrosion resistance and behaviour under radiation from thermal neutrons. A brief survey is then made of steels used for the inner and outer parts of the reactor nucleus within the primary circuit, protecting screens, etc.

Development of uranium nitride stainless steel dispersion fuel elements S. J. Paprocki, D. L. Keller, G. W. Cunningham, and A. K. Foulds jun. (*BMI*–1365, 1959, July 31, pp.22; from *Nucl. Sci. Abs.*, 9159, **13,** Nov. 15, 2579) Work to produce stainless steel-clad flat-plate fuel elements having a core of 28 w/o UN dispersed in an Fe–18 w/o Cr–14 w/o Ni–2·5 w/o Mo matrix is described. Optimum fabrication conditions were determined.—D.L.C.F.

On steel tube for nuclear power plant G. Kojima and E. Miyoshi (*Sumi. Met.*, 1959, **11,** July, 224–231) A review, dealing mainly with finned fuel-element cans for various American and British reactors.—K.E.J.

Some metallurgical features of nuclear reactors H. M. Finniston (*Brit. Nucl. Energy Conf.*, 1960, **5,** Jan., 37–48) The requirements on stainless steel for use as a canning material are mentioned and the behaviour of structural materials including a number of steels during and after irradiation is discussed at length. Irradiation affects the tensile properties, it increases hardness, and reduces ductility, the latter is usually associated with a rise in the ductile–brittle transition temp.—T.G.

HISTORICAL

The iron industry in Roman Britain S. Hawkes (*Appleby Frodingham News*, 1959, **12,** (2), 24–29) Notes on mining and smelting in Roman times.

The Darbys of Coalbrookdale A. Raistrick (*Endeavour*, 1959, **18,** Oct., 186–190) An illustrated historical account (10 refs).

The British iron and steel industry from 1870–1914 G. Grenier (*Mines Mét.*, 1960, Feb., 79–81) A review of steelmaking in general terms.

The repair of the St. Michel furnace: a relic of our ancient metallurgy W. Lassance (*Fond. Belge*, 1960, **30,** Jan., 3–7).

The GKN Group of companies E. B. Thomas (*Steel Rev.*, 1960, (17), 40–48) Historical.

ECONOMICS AND STATISTICS

World steelmaking heads into an era of major change G. J. McManus (*Iron Age*, 1959, **184,** Dec. 31, 17–19) Commercial and technical trends in the steelmaking industry of the world's major producing countries are surveyed. Development of modern practice and selling methods in Europe and increasing Russian capacity are noted. Foreign competition to American steel is expected to grow.

The location of modern iron and steel works at the sea coast A. H. Ingen Housz (*Stahl Eisen*, 1960, **80,** March 3, 272–276) The economic advantages—mainly in freight of the raw materials and—if export to overseas countries is expected—also for the finished products—of the location of iron and steel-works at the sea coast are discussed. These advantages are particularly evident as all the materials are heavy and as very large quantities are involved. Other problems such as energy supply, sales of by-products, water supply, and air pollution are included in this discussion.—T.G.

Poland's iron and steel industry A. Mroczkowski (*Iron Steel Rev.*, 1959, **3,** Sept., 27–36) A statistical account.

Operational research in the steel industry R. H. Collcutt (*Iron Coal Trades Rev.*, 1960, **180,** Jan. 22, 189–196) A review of the operational research studies carried out in the British iron and steel industry is given and a number of case histories are quoted.—T.S.

MISCELLANEOUS

Maintenance and productivity, the measurement of maintenance effort and costs (Sir) Charles Goodeve (*BISRA 8th Conference on engineering maintenance, Westminster*, Dec. 1952, 3). **Plant recommendations for the future** B. Gray (4–5, discussion, 6–11). **General organization—points for improvement, relation of production and maintenance departments** A. Bridge (12–13). **Preventive maintenance, repair methods, facilities and spares** G. Oram (14–17). **Engineering maintenance—manning problems** J. Wadsworth (18–19, discussion 20–24).

Rope winding in England and its introduction in Germany D. V. Ebeling (*Glückauf*, 1959, **95,** Aug. 1, 989–1001). **The rope winding installation in shaft No.5 of the Emsther–Lippe colliery** F. Steiner (1001–1002). **Safety aspects for the application of rope winding in shafts** H. Borger (1003–1005) Properties and care of the cables are included.

Electrical conductivity of molten FeS Argyriades, G. Derge, and G. M. Pound (*Trans. Met. Soc. AIME*, 1959, **215,** Dec., 909–912) The electrical conductance of molten FeS was studied as a function of temp. and composition. Stoichiometric (36·5%S) FeS shows a minimum specific conductance of 400/Ω.cm. The increase in conductivity towards the Fe-rich side is greater than that to the S-rich composition. Molten stoichiometric FeS is an intrinsic semi-conductor of narrow forbidden energy gap. S acts as acceptor and Fe as donor impurity.—T.G.

Some metallurgical and statistical aspects of the manufacture of grinding balls N. V. Hunt (*BHP Tech. Bull.*, 1959, **3,** Sept., 15–19) The application of quality control methods to the mechanical production of grinding balls is described and directions for possible improvements assessed.—S.H.–S.

The operation of sulphuric acid plants with iron reactors J. Nicoletis (*Génie Chim.*, 1959, **82,** July (Supplement), 14–19) The principle of the processes involved are discussed—oxidation of SO_2 by nitrogen oxides—and their operation is described.

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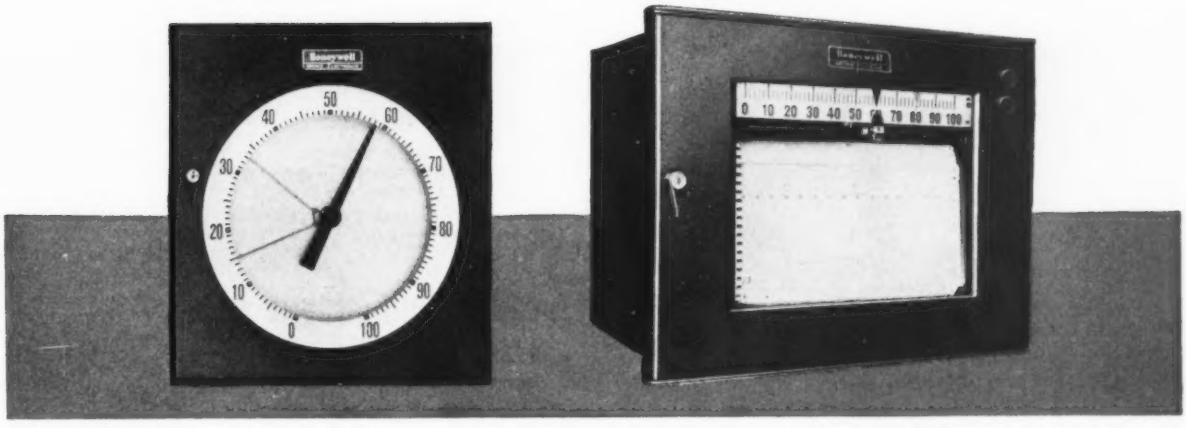

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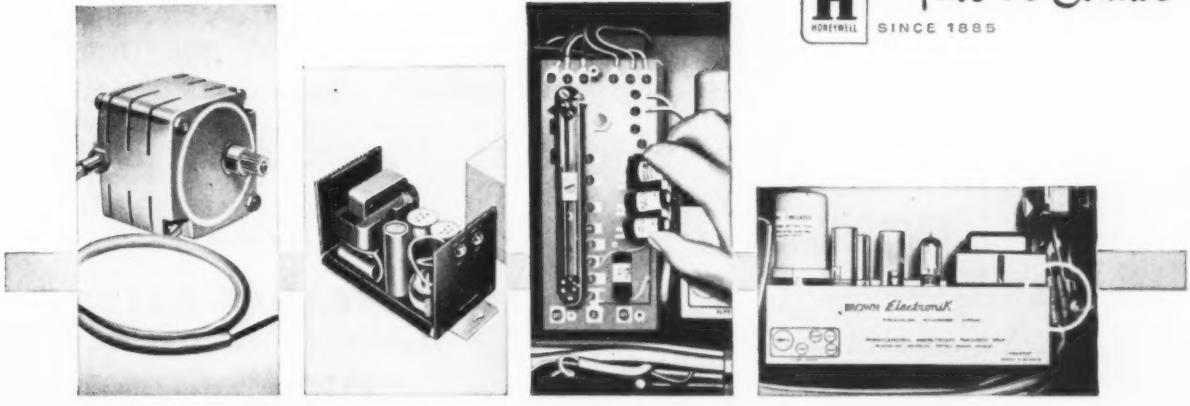

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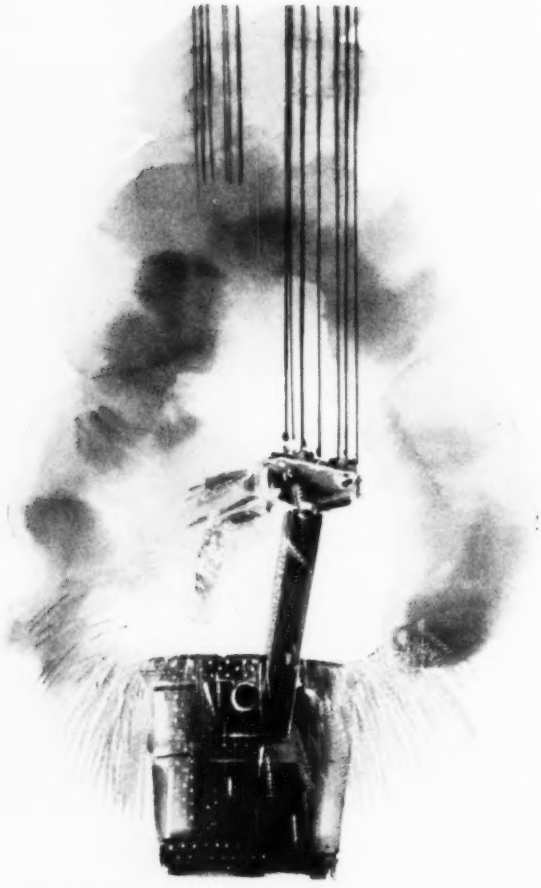

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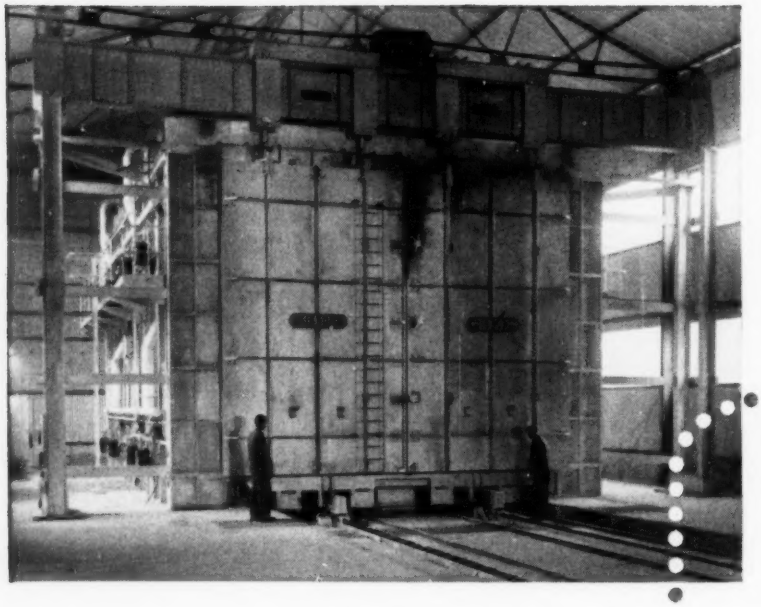

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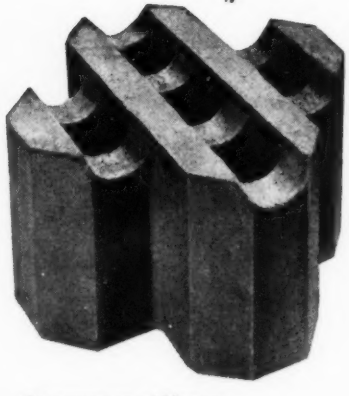

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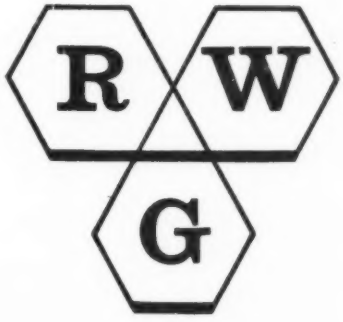

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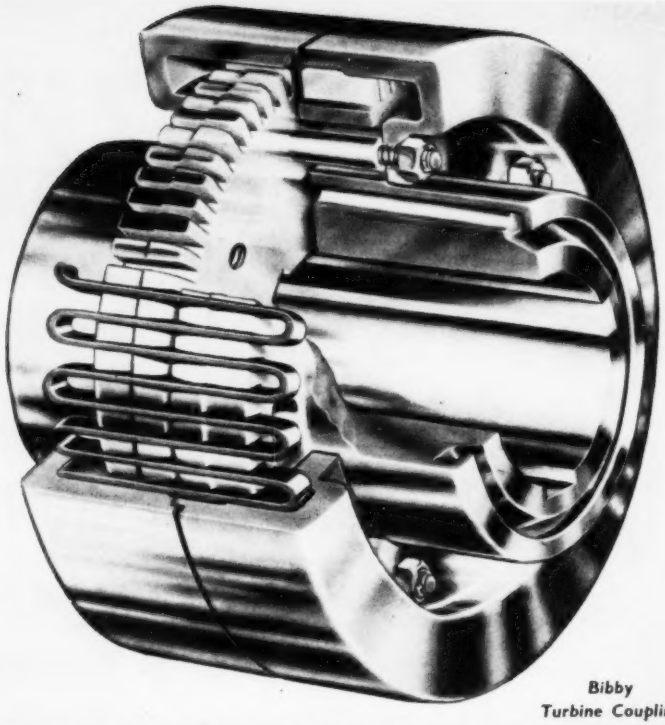

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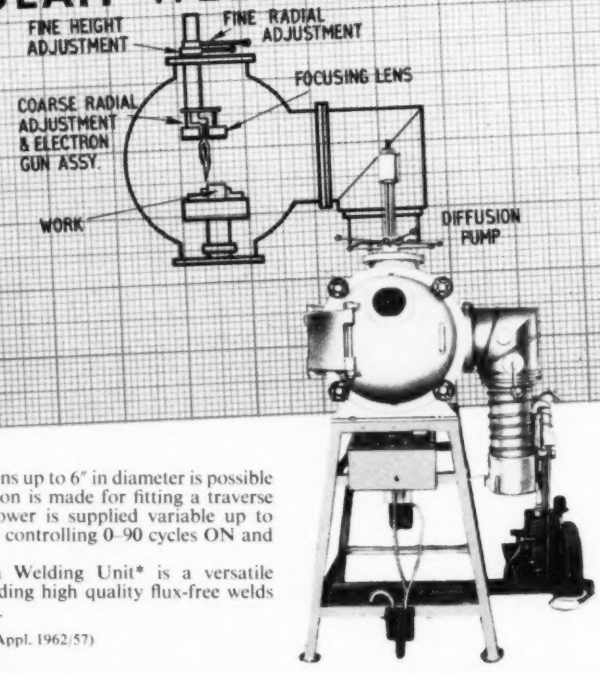

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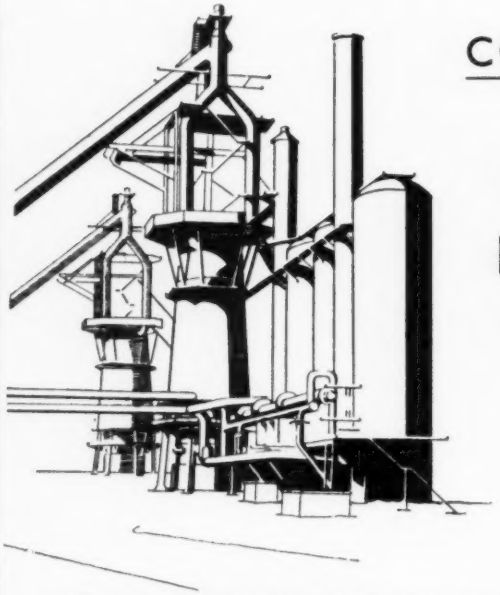

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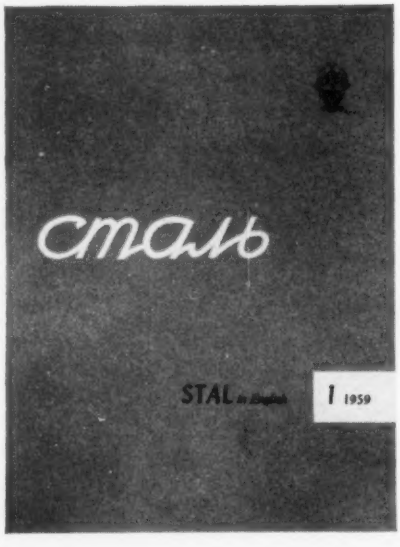

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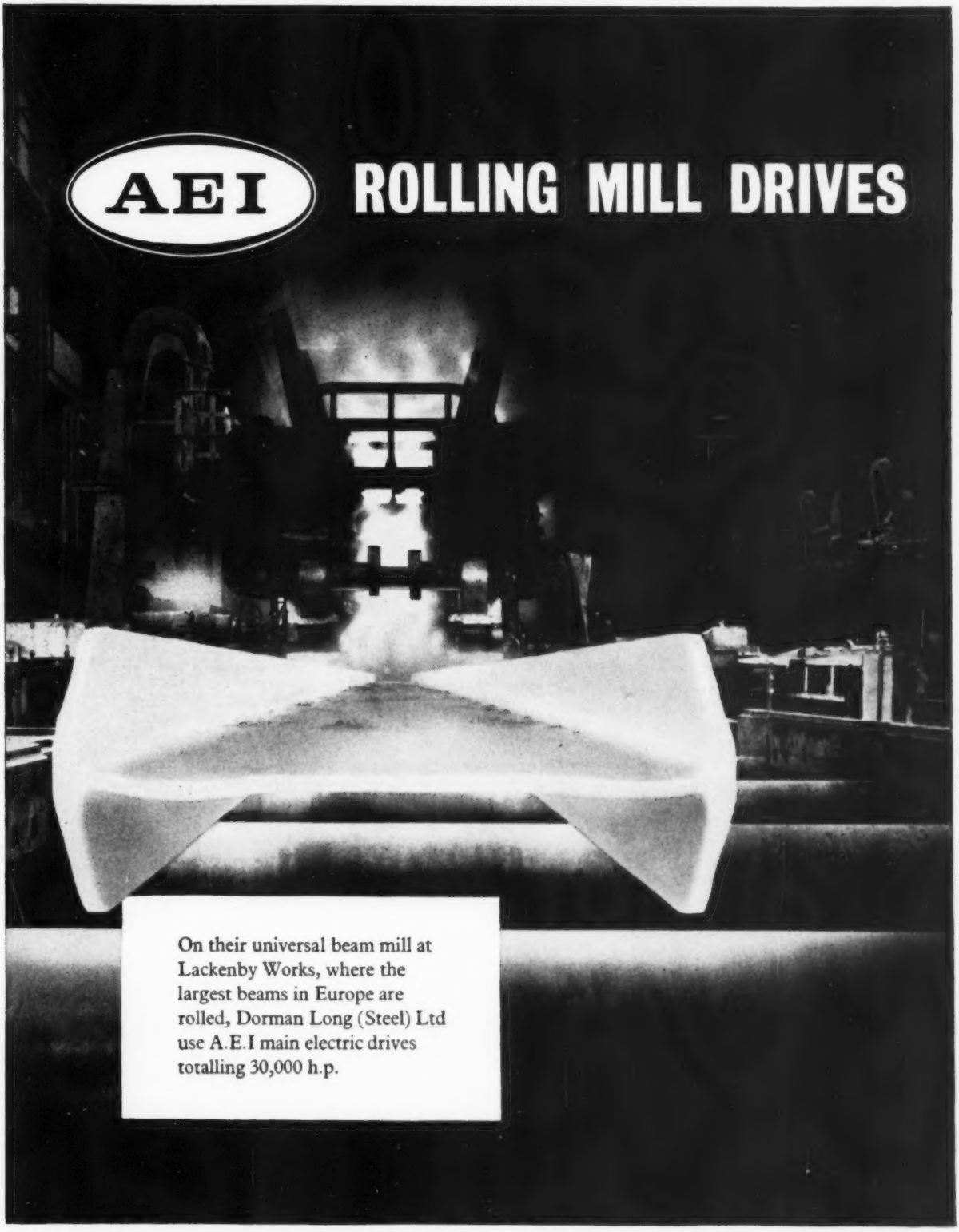
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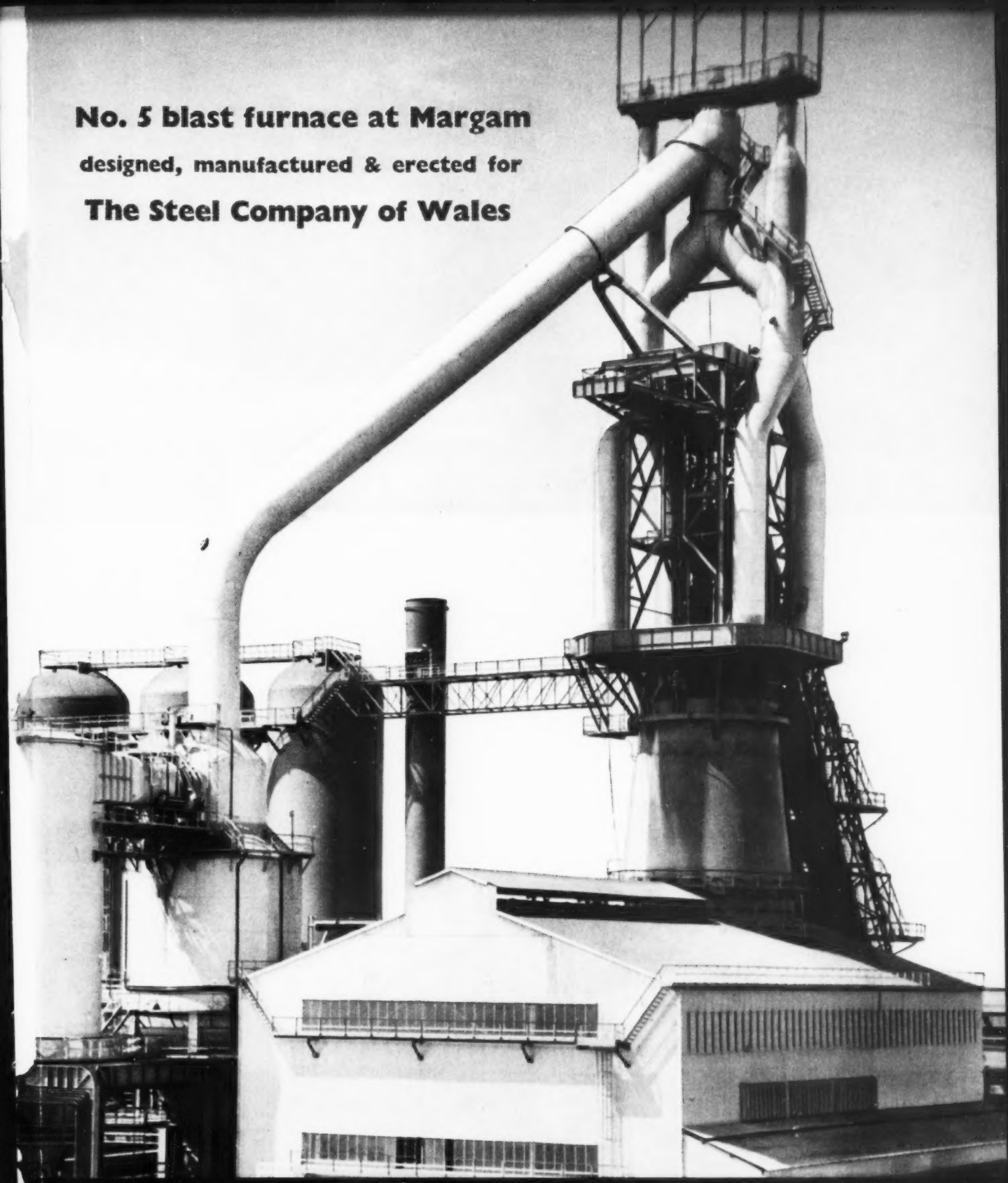


No. 5 blast furnace at Margam

designed, manufactured & erected for

The Steel Company of Wales

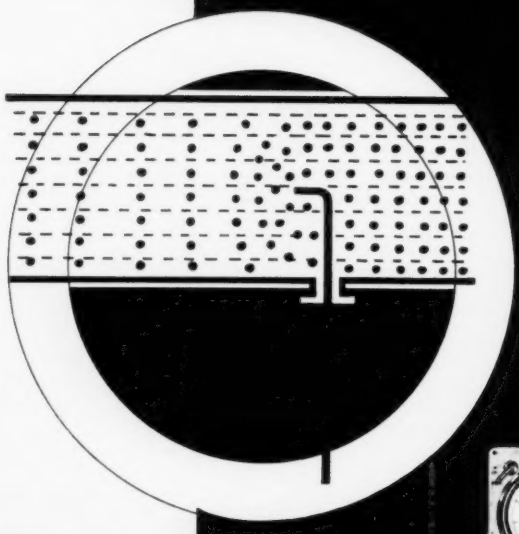
ASHMORE, BENSON, PEASE & COMPANY LIMITED

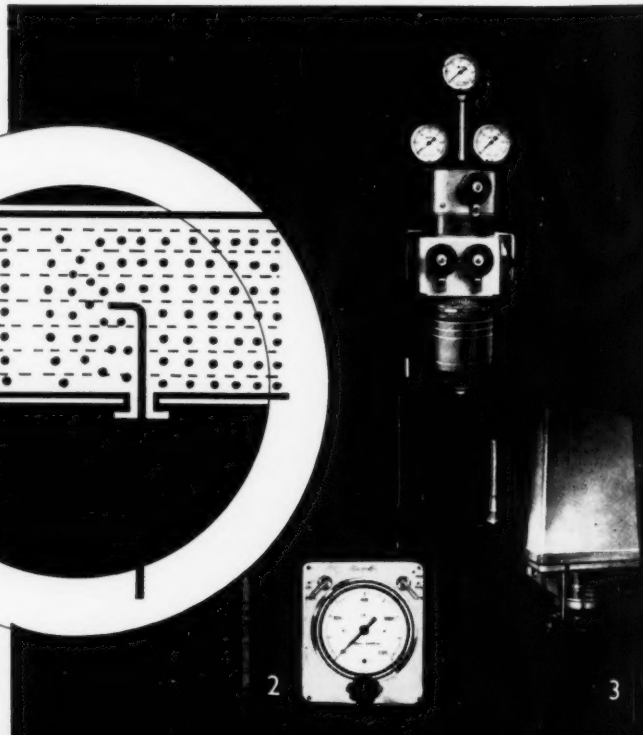
STOCKTON-ON-TEES AND LONDON

MEMBER OF THE

POWER-GAS GROUP

BLAST MOISTURE CONTROL





2 3

1. Model 3000-8 Remote Set Three-term Air-operated Force-balance Process Controller.

2. Model 3000-12 Indicating Control Station.

3. Model 3000-16 Pneumatic Force-balance Temperature Transmitter.

In the continual search for new methods of improving blast furnace performance, control of the quantity of moisture in the blast has been found to result in smoother operation and higher output whilst also providing a means of rapidly influencing furnace conditions. In collaboration with customers' engineers Electroflo have developed a system of automatic control which will maintain the moisture content of the cold blast at a constant value. This system is based on wet and dry bulb measurements on a sample taken continuously from the cold blast main. The moisture addition is strictly in accordance with the rate of blowing and is easily varied to suit changes in operating conditions. The system employs Electroflo Series 3000 automatic temperature controllers and transmitters

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